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Fluidized bed drying.

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FLUIDIZED BED DRYING

By

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FLUIDIZED BED DRYING

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ABSTRACT

The use of a fluidized bed dryer to dry acrylonitrile-butadiene-styrene terpolymer was studied. Data for fluidized bed drying were obtained from the Monsanto Company's fluid bed dryer. Fluid bed theory, drying phenomena, and fluid bed drying limitations were investigated.

With the theory of fluidization and drying, a mathematical model of the system was derived and a computer program to perform the simulation was written. The program varied temperature of inlet air, humidity of the inlet air, and inlet air flow rate. The program was run for eight different operating conditions involving changes in inlet solid moisture content, outlet solid moisture content, and inlet solid flow rates.

The model suggests that the Monsanto dryer may have too short a residence time. The possibility of increasing the solid flow rate to the dryer was also investigated. Increasing solid flow rate to the dryer would cause a significant amount of particle entrainment.

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NOMENCLATURE

A	area of particle available for drying, m^2
A_s	bed surface area, m^2
Ar	Archimedes number, dimensionless
b	empirical constant, unitless
c	empirical constant, unitless
C_d	empirical drag coefficient, dimensionless
C_{pg}	specific heat of the gas, cal/gm-^oC
C_{pL}	specific heat of dry gas, cal/gm-^oC
C_{ps}	specific heat of dry solid, cal/gm-^oC
C_{pw}	specific heat of the walls, cal/gm-^oC
d_n	particle diameter on screen n, m
d_{n+1}	particle diameter on screen n+1, m
$\bar{d}_n$	average diameter between screen n and n+1, m
$\bar{d}_h$	harmonic mean diameter, m
d_p	particle diameter, m or ft
$\bar{d}_w$	weight mean diameter, m

$\mathcal{D}_v$	diffusivity, cm^2/sec
E(t)	exit age distribution
g	acceleration of gravity, 980 $cm/(sec)^2$
g_c	conversion factor, 980 $gm\text{-}cm/(gm\text{-}f)(sec)^2$
G_{mf}	minimum fluidization gas mass velocity, $lb/hr\text{-}ft^2$
G	air flow rate, kg air/sec
G_s	air flow rate, kg dry air/sec
h	expanded bed height, m
h_g	heat transfer coefficient, $cal/cm^2\text{-}sec\text{-}^oC$
h_o	packed bed height, m
H_{G1}	enthalpy of inlet gas at T_{G1}, cal/kg dry gas
H_{G2}	enthalpy of outlet gas at T_{G2}, cal/kg dry gas
H_{L1}	enthalpy of inlet solid at T_{L1}, cal/kg dry solid
H_{L2}	enthalpy of outlet solid at T_{L2}, cal/kg dry solid
ΔH_A	integral heat of wetting at T_o, cal/kg dry solid
K	gas thermal conductivity, $cal/cm\text{-}sec\text{-}^oC$
L_{mf}	bed height at minimum fluidization, cm
L_s, L_1	solid flow rate kg dry/sec

m	empirical constant, unitless
$\dot{m}$	rate of evaporation of liquid from the solid surface, kg/sec
M_A	molecular weight of liquid, kg/kg mole
M_B	molecular weight of gas, kg/kg mole
n	empirical constant, unitless
Nu	Nusselt number, dimensionless
p_a	partial pressure of liquid vapor at a given temperature, Pa
P_t	total pressure, Pa
ΔP	pressure drop, gm/cm^2
Pr	Prandtl number, dimensionless
Q	heat, cal/sec
Q_1	heat to evaporate H_2O, cal/sec
Q_2	heat to raise temperature of H_2O, cal/sec
Q_3	heat to raise temperature of solid, cal/sec
Q_4	total heat required for drying, cal/sec
Q_5	heat loss, cal/sec
Q_6	per cent heat loss, unitless
r	radius of particle, m

Re	particle Reynolds number, dimensionless
S_A	cross-sectional area of the equipment, m^2
Sc	Schmidt number, dimensionless
Sh	Sherwood number, dimensionless
t	time, sec
t_c	time at the critical moisture content, sec
T_{AIR}	ambient air temperature, K
T_i	interfacial temperature, K
T_o	reference temperature, K
T_G	gas temperature, K
$\bar{T}_G$	log-mean temperature of the gas, K
T_{G1}, T_3	inlet gas temperature, K
T_{G2}, T_4	outlet gas temperature, K
T_{L1}, T_1	inlet solids temperature, K
T_{L2}, T_2	exit solids temperature, K
u	superficial gas velocity, cm/sec
u_{mf}	minimum fluidization velocity, cm/sec
u_t	terminal velocity of a falling particle, cm/sec

V_g volume of gas, cm^3

V_s volume of particles, m^3

V_v total volume of bed, m^3

W_g mass weight of bed, kg

W_w mass weight of the walls, kg

x moisture content, kg moisture/kg dry solid

$\bar{x}$ average moisture content, kg moisture/kg dry solid

x_c critical moisture content, kg moisture/kg dry solid

x_1 initial moisture content, kg moisture/kg dry solid

x_2 final moisture content, kg moisture/kg dry solid

$X(t)$ drying rate curve

y_1 inlet humidity (air), kg H_2O/kg dry air

y_2 outlet humidity (air), kg H_2O/kg dry air

Y absolute humidity, kg/kg

z direction of diffusivity, cm

Z hold-up of material in the dryer, kg

GREEK LETTERS

ε	bed voidage, m^3/m^3
ε_{mf}	bed voidage at minimum fluidization, m^3/m^3
θ	gas temperature, ^oC
λ_i	heat of vaporization at T_i, cal/kg H_2O
λ_o	heat of vaporization at T_o, cal/kg H_2O
μ	viscosity of the gas, gm/cm-sec
ρ_g	density of gas, gm/cm^3
ρ_s	density of solid particles, gm/cm^3
τ	mean residence time in the dryer, sec
ϕ_s	sphericity of the particle, dimensionless
$\Delta\phi_n$	weight fraction of diameter $\bar{d}_n$

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I. INTRODUCTION

The fluidized bed has become widely used in drying systems in recent years. Fluidized bed dryers have been used for drying granular materials, pastes, solutions, suspensions, and molten materials in both a batch and a continuous dryer[1].

In a fluidized bed dryer the bed is composed of the moist material to be dried with the fluidizing medium being hot gas. High heat and mass transfer rates are encountered due to the intimate contact between the hot gas and the solids. When unbound moisture is present, the high heat transfer rates result in an instantaneous evaporation[2], causing a rapid fall in the gas temperature above the grid of the dryer as well as a decrease in particle temperature. The rapid heat transfer allows for higher inlet gas temperatures when drying temperature sensitive materials[3].

The mixing of the solids within the bed approaches ideality[4]. The solid particles are in a state of uninhibited motion. All particles have access to any part of the dryer at any point in time, limited only by the flow of gas. The efficient mixing of the solid particles gives a high degree of uniformity in the moisture content of the exiting solids[5]. The air velocity is extremely important since it determines the degree of fluidization. The velocity must be greater than that required for incipient fluidization and below the point that would promote major entrainment. The velocity must also be low enough so as not to promote bubbling or slugging within the bed. The air velocity used is a function of particle size and particle density. The particle size distribution of the outlet stream is almost identical to that of the inlet due to "air cushioning" between the particles.

While fluidized bed dryers have many advantages when used in continuous operation, there are special[6, 7] problems that may make the dryer difficult to operate. The particles must be able to be fluidized at realistic air flow rates. The particles must have a relatively small range of particle sizes to minimize entrainment and maximize moisture content uniformity. The drying of particles with long falling-rate curves is extremely difficult in fluidized bed dryers. Due to large pressure drops across the distributor, bed, and cyclones, a large power requirement for the blower is encountered. Finally there has been to date no proven method for scale-up from pilot plant size.

The Monsanto Company produces acrylonitrile-butadiene-styrene terpolymer (ABS) at their Port Plastics Plant in Addyston, Ohio. It is dried in a fluidized bed dryer. The performance of the dryer has not been adequate in that the desired product moisture content has not been reached. This may be due to the characteristics of the particle, inadequate design, or improper operation conditions. The objective of this study is to examine fluidized bed drying and to present a preliminary mathematical model of a continuous fluid bed dryer to substantiate the operation of Monsanto's dryer.

II. FLUIDIZATION

A fluidized bed is a process which contains solid particles through which a fluid is passed and the bed is in a state which attains properties similar to those of fluids. The velocity of the fluid, when a gaseous fluidizing media is used, must be slightly higher than the minimum fluidizing velocity (in all further discussion the fluid will be a gas).

A. Fluidization Phenomena

The velocity of the air passing through the bed of solids will determine the state of the bed as shown in Figure 1. At low gas flow rates, the gas passes through the void areas of the bed without disturbing any of the particles; this is a fixed bed (Figure 1A).

With an increase in the gas flow rate the particles within the bed begin to move; this is an expanded bed. By continuing to increase the flow rate of the gas, the pressure drop across the bed increases; when the frictional drag between the particle and gas becomes equal, the pressure drop will level off[8]. At this point the bed is said to be at minimum fluidization with the velocity of the fluid being the incipient fluidization velocity or minimum fluidization velocity (Figure 1B). If the air flow rate is increased above the minimum fluidization velocity, the bed will continue to expand in a smooth manner. The particles within the bed begin to intermix and freely traverse the

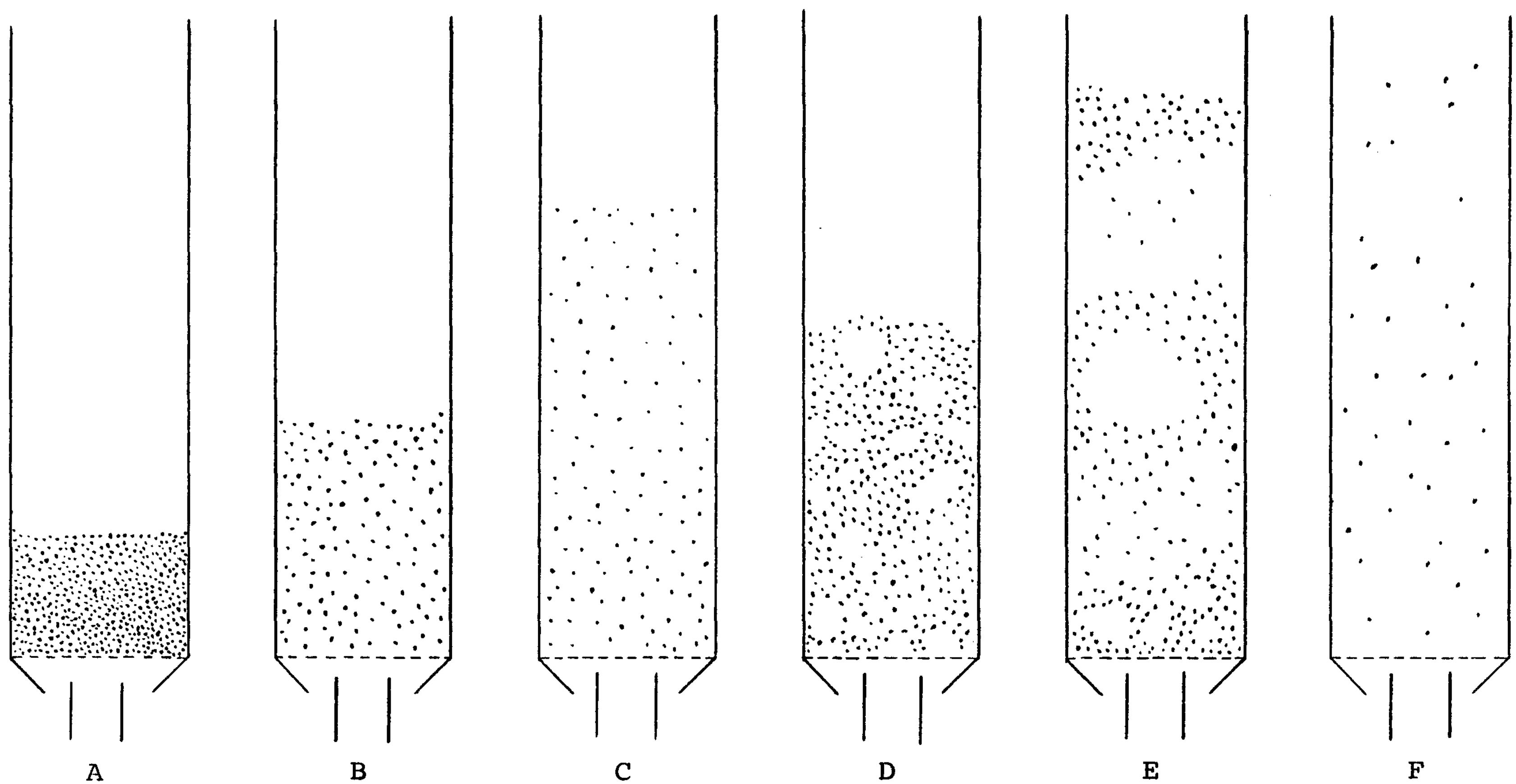

FIGURE 1. TYPES OF FLUIDIZED BEDS

area within the bed. When the bed has a clearly defined upper limit, the fluidized bed is said to be a dense-phase fluidized bed[9] (Figure 1C).

As the gas flow rate increases so does the height of the bed. When the height of the bed is greater than the container, the particles are carried over by the gas and the particles are said to be entrained.

A fluidized bed is usually operated between the incipient fluidization velocity and the entrainment velocity. Optimal conditions exist when the concentration of solid particles is uniform throughout the bed and constant with time[10]. If there is a major difference in the densities of the solid and gas, there may be a minimum number of conditions at which adequate fluidization may be attained. In using gas as the fluidizing medium for fluidization, the gas velocity is not much greater than that of the incipient fluidizing velocity, and only certain materials will be able to be properly fluidized[11] due to size distribution, shape factor, density, suitability, etc.

As the flow rate is increased beyond the minimum fluidization point, large instabilities within the bed are often encountered. The system is then said to be an aggregative fluidized bed and will have such instabilities as bubbling and channeling of the gas. If the flow rate is increased even higher, the rates of agitation will become very violent and the movement of the solid will be vigorous.

Aggregative fluidized beds are only of theoretical interest, and for the purpose of drying of solids, these conditions should be avoided since the quality of fluidization falls during aggregative fluidization[12]. As the quality of fluidization declines, gas bubbles begin to form within the fluidized bed. When the bubbles reach a size much larger than the suspended particles, but smaller than the dimensions of the vessel, the bed is said to be bubbling (Figure 1D). Factors that cause a bubbling bed are air velocity, bed geometry, gas distributor, and the vessel internals[13]. If the size of the bubbles equals the whole cross-section of the containing vessel, the bed is then considered a slugging bed (Figure 15). The phenomenon of slugging is usually enhanced by vessel geometry. Slugging is particularly undesirable since entrainment of the particle becomes a major problem and the performance potential has been lowered.

Theoretically, by increasing the flow rate of the gas a fluidized bed would exhibit each of the phenomena shown in Figure 1. At increasing flow rates the amount of solids entrained would increase and would lower the particle concentration within the bed (assuming batch or constant inlet solid flow rate for a continuous bed). As the concentration is lowered the bed is no longer a dense phase fluidized bed, but instead it is now considered a dilute phase fluidized bed (Figure 1F).

B. Properties of the Fluidized Bed

A fluidizable material may have particles of the same size or with a distribution of sizes. If a material has a large size distribution, fluidization in the dense phase becomes difficult since entrainment of the smaller particles will occur at operating conditions. In analyzing the characteristics of the diameters of the particles, a screen analysis is often used. An arithmetic average is used to determine the diameter of the particle between two screens:

$$\bar{d}_n = \frac{d_n + d_{n+1}}{2} \tag{1}$$

where $\bar{d}$ is the average diameter between screen n and n+1, d_n is the particle diameter on screen n, and d_{n+1} is the particle diameter on screen n+1. When considering non-spherical particles, usually the second largest dimension of the particle is used.

For calculation purposes a single quantity must be determined as the characteristic diameter of the particle. In fluidization engineering two characteristic diameters have been used for different calculations[14]. These are:

the weight mean diameter

$$\bar{d}_w = \frac{\Sigma\ \Delta\phi_n\ \bar{d}_n}{\Sigma\ \Delta\phi_n} \tag{2}$$

and the harmonic mean diameter

$$\bar{d}_h = \frac{\Sigma \ \Delta\phi_n}{\Sigma \ \Delta\phi_n / d_n} \tag{3}$$

where $\Delta\phi_n$ is the weight fraction of diameter $\bar{d}_n$. For some calculations, ranges of particle diameters are used when more detailed considerations must be employed.

Another fundamental property of the fluidized bed is the minimum fluidization velocity. The onset of fluidization occurs when:

$$\begin{pmatrix}\text{drag force of}\\ \text{fluidizing gas}\end{pmatrix} = \begin{pmatrix}\text{weight of}\\ \text{particle}\end{pmatrix} \tag{4}$$

since

$$\begin{pmatrix}\text{drag force of}\\ \text{fluidizing gas}\end{pmatrix} = \begin{pmatrix}\text{pressure drop}\\ \text{across bed}\end{pmatrix}\begin{pmatrix}\text{cross-sectional}\\ \text{area of container}\end{pmatrix} \tag{5}$$

and

$$\begin{pmatrix}\text{weight of}\\ \text{particle}\end{pmatrix} = \begin{pmatrix}\text{volume}\\ \text{of bed}\end{pmatrix}\begin{pmatrix}\text{fraction of bed}\\ \text{containing solids}\end{pmatrix}\begin{pmatrix}\text{density}\\ \text{of solids}\end{pmatrix} \tag{6}$$

Substitute equations (5) and (6) into equation (4) and express in symbolic logic yields:

$$W = (\Delta P)(S_A) = (S_A L_{mf})(1 - \varepsilon_{mf}) \ (\rho_s - \rho_g)\frac{g}{g_c} \tag{7}$$

where

- W = weight of bed in kg

- ΔP = pressure drop gm/cm^2
- S_A = cross-sectional area of container in cm^2
- L_{mf} = bed height at minimum fluidization in cm
- ε_{mf} = bed voidage at minimum fluidization, dimensionless
- ρ_s = density of solid particles in gm/cm^3
- ρ_g = density of gas in gm/cm^3
- g = acceleration of gravity, 980 $cm/(sec)^2$
- g_c = conversion factor, 980 $gm \cdot cm/gm \cdot (sec)^2$

Several correlations have been derived with equation (7) as the basis. Kunii and Levenspiel[15] proposed for small Reynolds numbers:

$$u_{mf} = \frac{(\phi_s d_p)^2}{150} \frac{\rho_s - \rho_g}{\mu} g \frac{\varepsilon_{mf}^3}{1 - \varepsilon_{mf}}; \quad Re < 20 \qquad (8)$$

where

- u_{mf} = minimum fluidization velocity in cm/sec
- ϕ_s = sphericity of the particle, dimensionless
- μ = viscosity of the gas in $gm/cm \cdot sec$
- Re = particle Reynolds number, dimensionless

and for large Reynolds numbers:

$$u_{mf}^2 = \frac{\phi_s d_p}{1.75} \frac{\rho_s - \rho_g}{\rho_g} g \varepsilon_{mf}^3; \quad Re > 1000 \qquad (9)$$

Wen and Yu[16] further simplified equations (8) and (9) through the following correlations:

$$\frac{1}{\phi_s\ \varepsilon_{mf}^{3}} \cong 14 \quad \text{and} \quad \frac{1 - \varepsilon_{mf}}{\phi_s^{2}\ \varepsilon_{mf}^{3}} \cong 11 \tag{10}$$

equations (8) and (9) now become:

for small Reynolds numbers:

$$u_{mf} = \frac{d_p^{2}(\rho_s - \rho_g)g}{1650\,\mu}; \quad Re < 20 \tag{11}$$

and for large Reynolds numbers:

$$u_{mf}^{2} = \frac{d_p(\rho_s - \rho_g)g}{24.5\,\rho_g}; \quad Re > 1000 \tag{12}$$

Equations (11) and (12) have been found accurate over a wide range of Reynolds numbers with a standard deviation of ± 34%[17]. Leva[18] proposed the following correlation based on gas mass velocity:

$$G_{mf} = 688\ d_p^{1.82}\ \frac{(\rho_g(\rho_s - \rho_g))^{0.94}}{\mu^{0.88}} \tag{13}$$

where

- G_{mf} = minimum fluidization gas mass velocity in lb/hr-ft^2
- d_p = particle diameter in ft

- ρ_s = particle density in lb/ft^3
- μ = gas viscosity in centipoises

The most accurate estimation of the minimum fluidization velocity is through empirical methods. As stated before, at fluidization the pressure drop across the bed remains constant (Figure 2, line a). However, the grid resistance continues to increase with gas velocity (line b). Combining the effects of lines a and b, the total effect is line c and the minimum fluidization velocity may be determined. When plotted on log-log coordinates (Figure 3), the minimum fluidization velocity may be extrapolated with greater accuracy. Other less accepted methods involve bed voidage and/or bed height.

The minimum fluidization velocity determines the lowest gas flow possible, and the velocity of gas which causes entrainment of the solids is the upper gas velocity limit. The upper limit to gas flow rate may be approximated by the terminal velocity of the particle. From fluid mechanics the terminal velocity is given by:

$$u_t = \frac{4g\ d_p(\rho_s - \rho_g)^{\frac{1}{2}}}{3\rho_g\ C_d} \qquad (14)$$

where u_t is the terminal velocity of a falling particle in cm/sec and C_d is an experimentally determined drag coefficient (dimensionless). Various correlations may be made between the ratio of the terminal velocity and the minimum

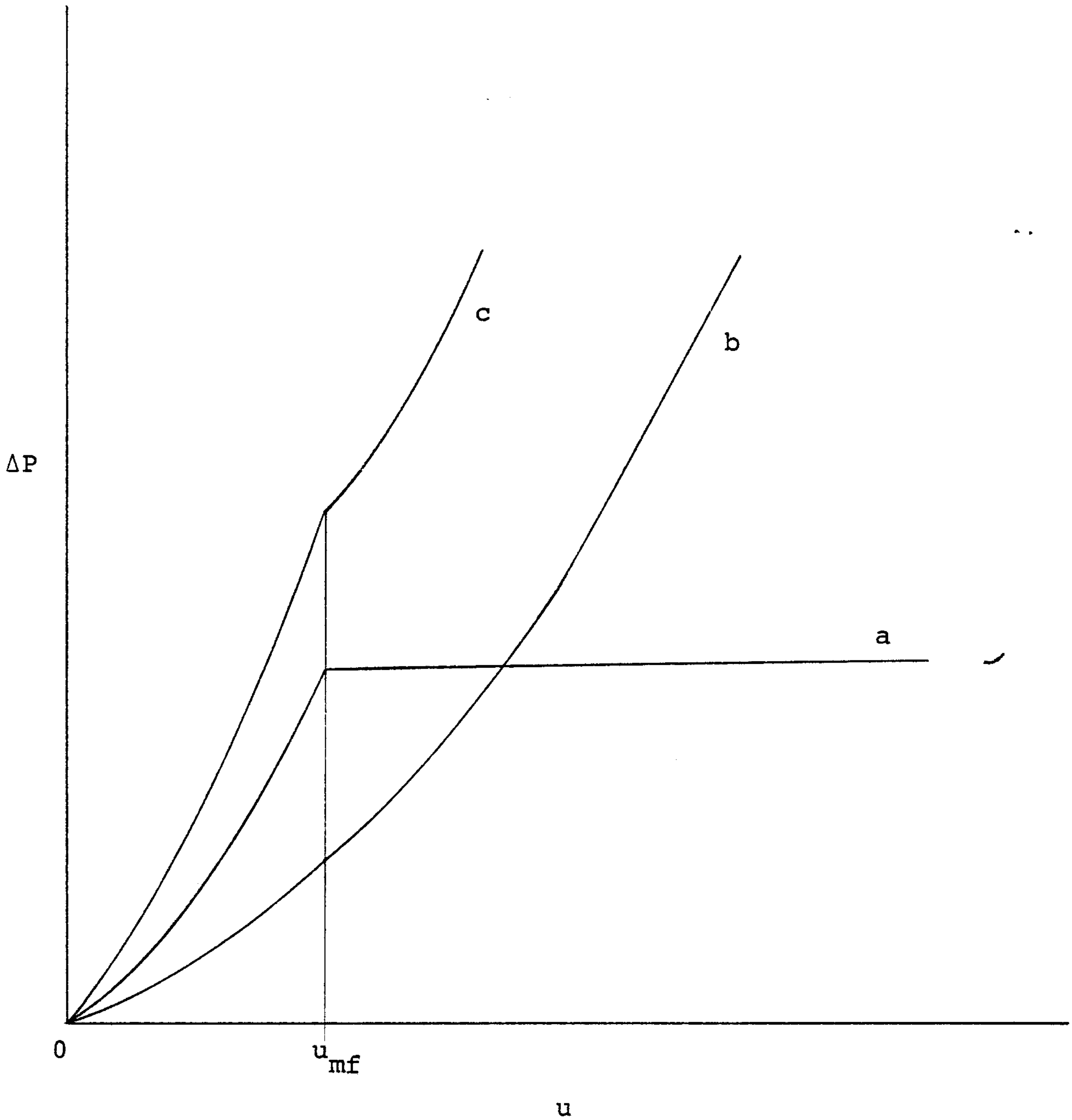

FIGURE 2. GRID RESISTANCE

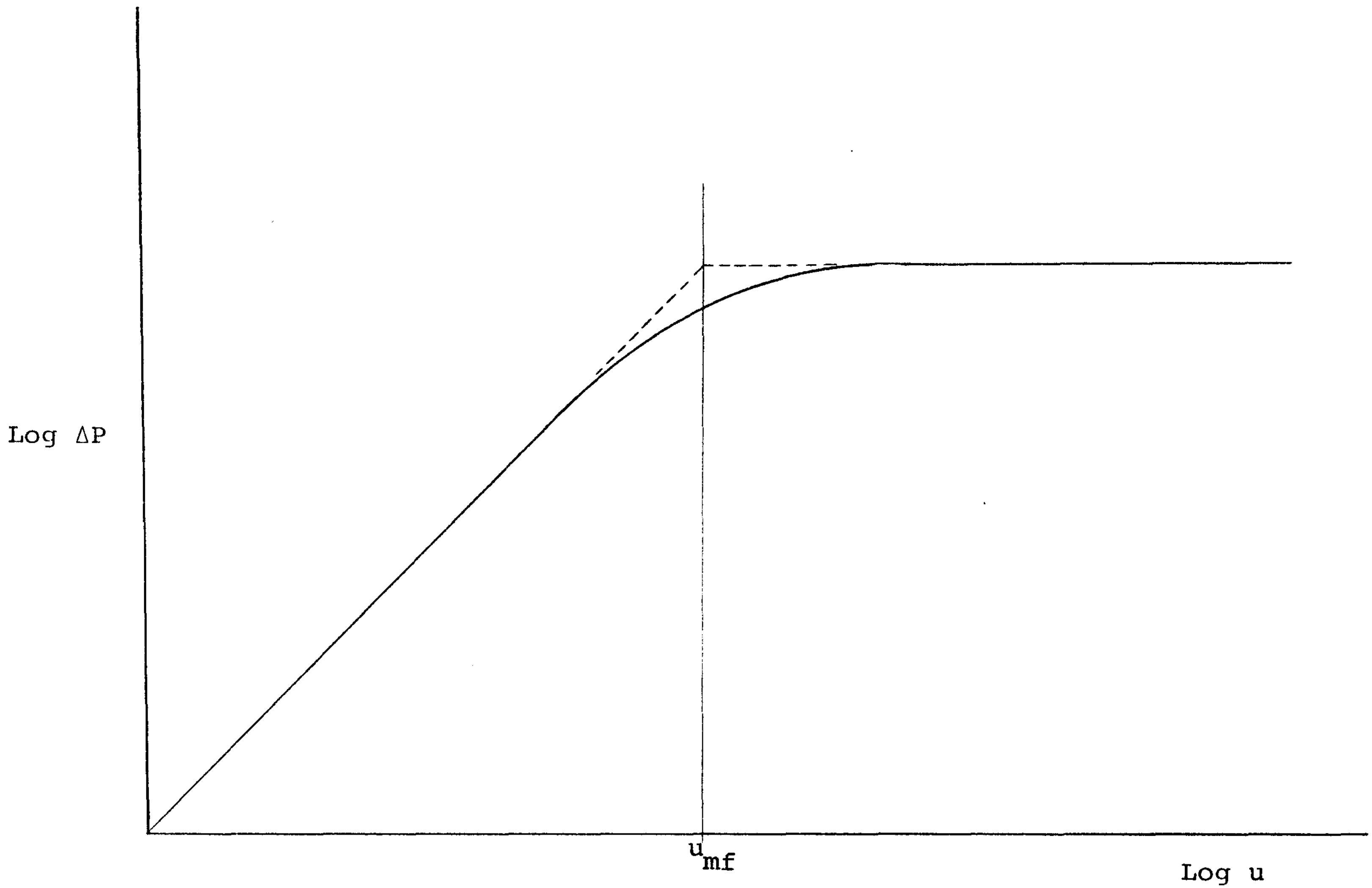

FIGURE 3. THE DETERMINATION OF THE INCIPIENT FLUIDIZATION VELOCITY AS A FUNCTION OF GRID RESISTANCE

fluidization velocity[21], but adequate substantiation of these ratios has yet to be proven.

By changing the operating velocity, the porosity or bed voidage will also be changed. The bed voidage is the ratio of the volume of free space in the bed to the total volume of the bed. Thus porosity may be described by the following equation:

$$\varepsilon = \frac{V_v - V_s}{V_v} = 1 - \frac{Z}{\rho_s V_v} \tag{15}$$

where

- ε = bed voidage
- V_v = total volume of bed in m^3
- V_s = volume of particles in m^3
- Z = hold-up of material in the dryer in kg

For a cylindrical bed

$$V_v = S_A h \tag{16}$$

where

- S_A = cross-sectional area of the equipment in m^2
- h = expanded bed height in m

If $h_o = Z/S_A\rho_s$ for a given operation condition, with h_o the packed bed height at this condition, equation (15) becomes

$$\varepsilon = 1 - \frac{h_o}{h} \tag{17}$$

If numerous run conditions are not available, then the bed voidage may be calculated from the Todes, Goroshko, and Rozenbaum correlation[22]:

$$\varepsilon = Ar^{-21} \left(18\ Re + .36\ Re^2\right)^{0.21} \qquad (18)$$

where Ar is the dimensionless Archimedes number:

$$Ar = g(d_p)^3\ (\rho_s - \rho_g)/((\mu/\rho_g)^2\ (\rho_g)) \qquad (18a)$$

The main value of the porosity calculation is for the calculation of the height of the bed. It should be noted that under run conditions the bed voidage will vary with bed location and time.

III. DRYING

The purpose of drying a solid is to remove a liquid by converting the liquid to a vapor which may easily be separated from the solid. The energy for the conversion of liquid to vapor is, in a majority of cases, thermal energy. Heat is transferred predominately by conduction and convection with a minor degree of radiation.

During the thermal drying process two types of transport phenomena are occurring simultaneously: (1) heat is transferred to the solid to raise the solid temperature and evaporate moisture; (2) mass is transferred from inside the particle to the particle surface and then evaporated. The drying rate is determined by how fast these two processes occur. The specifics of heat and mass transfer will be discussed in the Fluidized Bed Drying section. The actual drying rate of a material must be determined empirically; it cannot be predicted theoretically[23].

A. Drying Periods

The rate of drying is usually determined from a drying test[24]. A number of drying runs are to be made in a piece of equipment similar to the type of dryer proposed. Several variables are used to determine the optimum conditions for the drying of the solid, namely: temperature, air flow, material characteristics, and air humidity. For a given set of conditions a curve of moisture content as a function of time is plotted (Figure 4).

The data obtained from an experimental run are usually converted into rates of drying for better clarification of the drying characteristics of the particles involved. Rates of drying (N) are expressed in kg moisture evaporated/(sec)(m^2), and plotted against moisture content (Figure 5). A majority of materials are surface-set and will show three distinct regions in the drying-rate-curve. The initial region is section AB where the material is warming up; section BC where the rate of drying is constant; and section CD where the rate of drying decreases. Section BC of the curve is referred to as the period of constant drying where the unbound surface moisture is evaporated. Section CD is referred to as the falling drying rate where bound moisture, internal and unsaturated surface moisture, is removed. Point C, where the constant rate ends and the falling rate begins, is termed the critical moisture content.

B. Psychrometric Considerations

As previously stated, heat and mass transfer occur simultaneously during the thermal process of drying. The actual quantities of air required to remove the evaporated moisture may be determined from psychrometric charts. Psychrometric charts for a variety of gas liquid combinations are available. The most common psychrometric chart is that for the air-water system (Figure 6). Psychrometric charts for other components are similar with only the

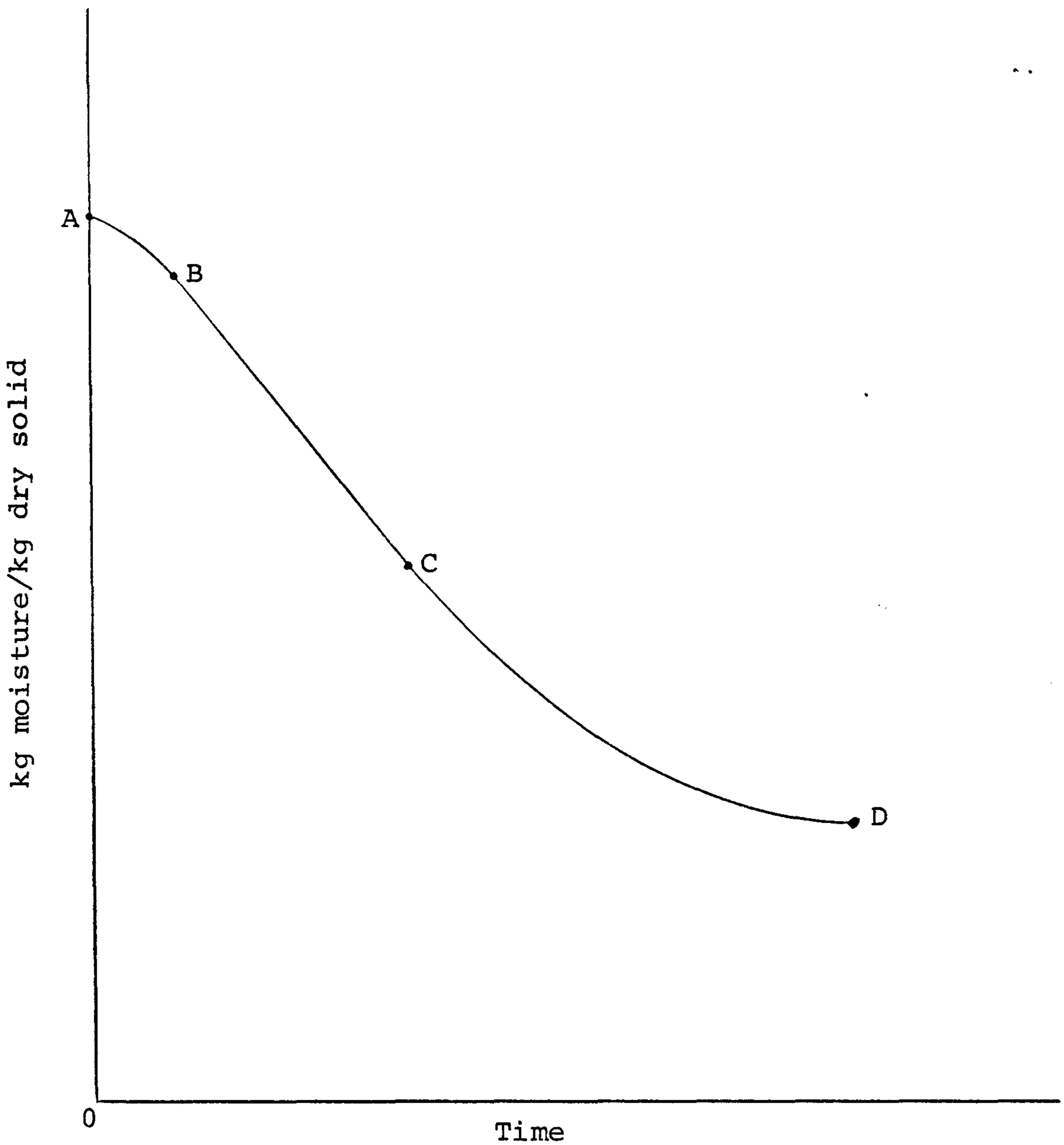

FIGURE 4. STEADY STATE DRYING

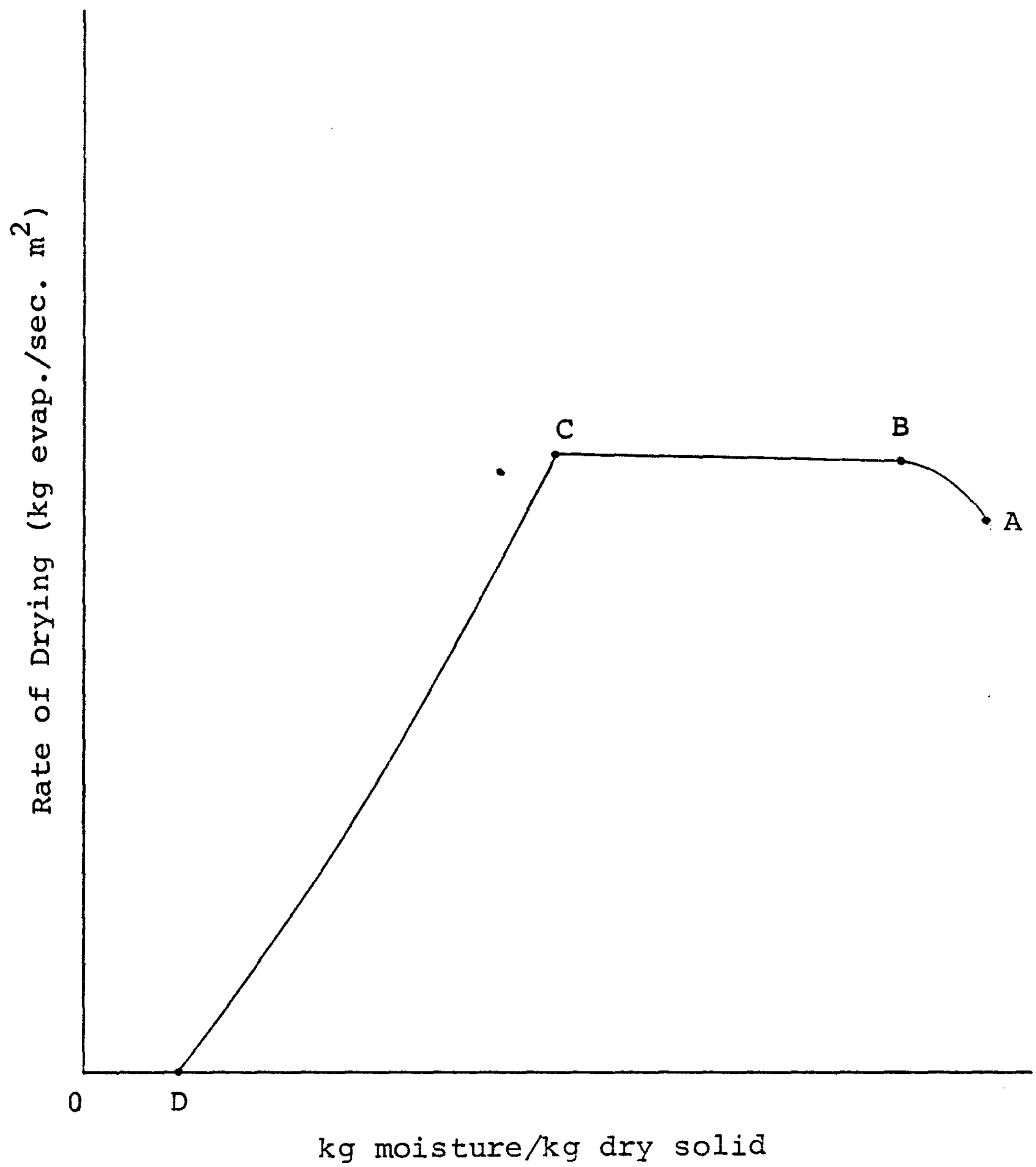

FIGURE 5. TYPICAL RATE-OF-DRYING CURVE

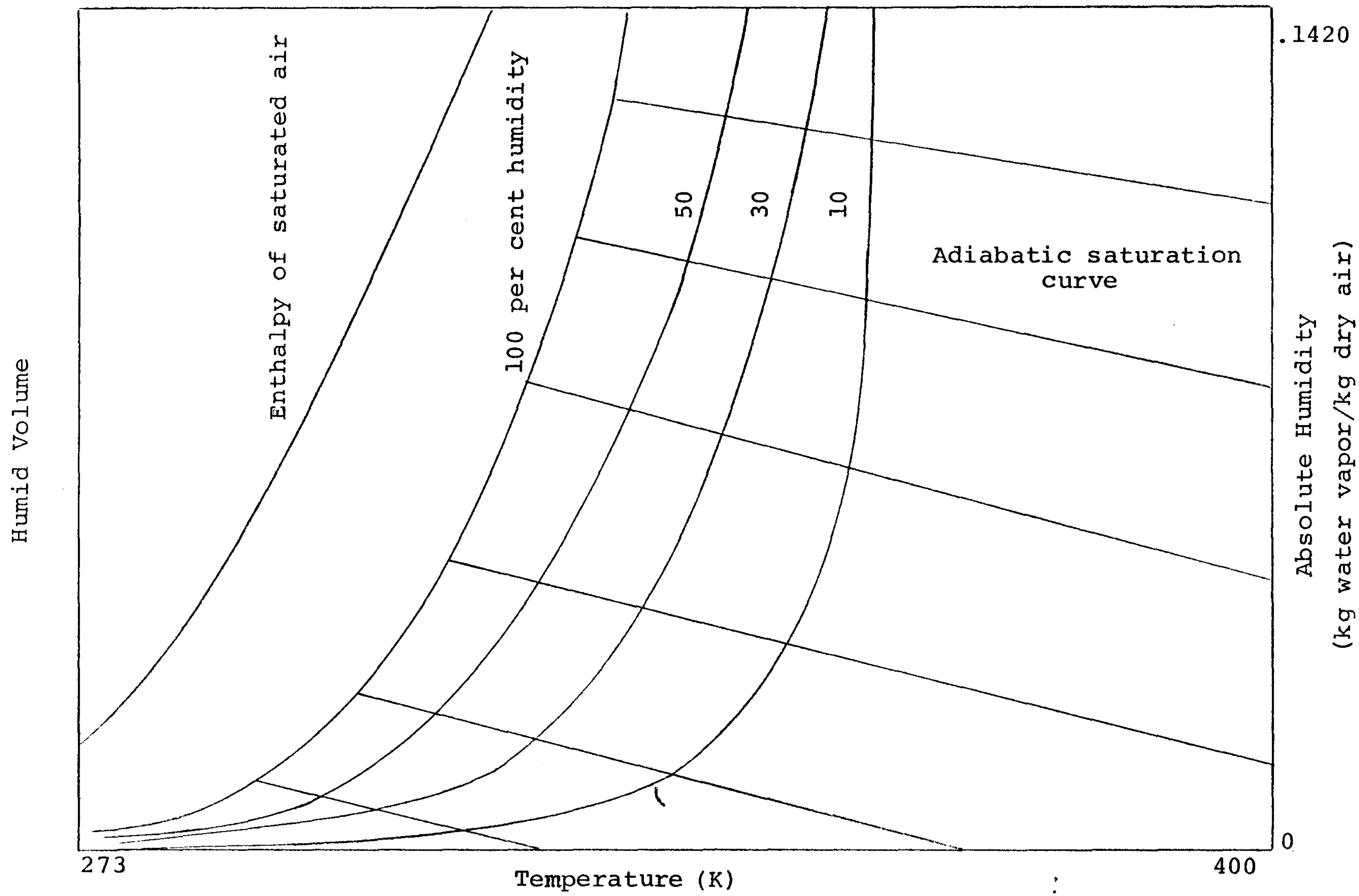

FIGURE 6. ABBREVIATED PSYCHOMETRIC CHART

values changing. The following are definitions important in psychrometry.

Absolute humidity is the ratio of the mass of vapor to mass of vapor free gas.

$$y = \frac{p_A}{P_t - p_A} \frac{M_A}{M_B} \tag{19}$$

where

- y = absolute humidity in (Kg/Kg)
- p_A = partial pressure of water vapor at a given temperature in pascals
- P_t = total pressure in pascals
- M_A = molecular weight of liquid in Kg/Kg mole
- M_B = molecular weight of gas in Kg/Kg mole

In psychrometric charts absolute humidity is plotted against dry-bulb temperature.

Dew point is the temperature to which a vapor-gas mixture must be cooled (at constant humidity) to become saturated. Adiabatic-saturation curves are essentially linear curves on the psychrometric chart which start at the saturation curve and continue to the right. These lines correlate the fact that when air of a given humidity cools adiabatically in contact with water at the adiabatic saturation temperature of the air, its humidity increases; the fall in temperature and the rise in humidity follows the path of the adiabatic cooling lines. The adiabatic cooling curves assume that the system is 100% adiabatic and that the latent heat of evaporation may be accounted for completely by the temperature drop of the air stream with the adiabatic saturation temperature of the air stream being constant. However, heat losses are incurred in drying operations; therefore, the adiabatic cooling lines simply give a rough approximation of actual operating conditions.

IV. FLUIDIZED BED DRYING

Fluidized bed dryers are designed such that a hot gas enters at the base of the bed, passes through a distributor plate, and then into the bed of solids. Each particle is completely surrounded by the gas and has free movement throughout the bed - causing instantaneous mixing. Due to the complete mixing the temperature of the bed becomes uniform[26]. Fluidized bed dryers may be either batch or continuous; for the purposes of this paper, only the continuous process will be discussed.

A. Physical Characteristics

The design of a fluidized bed dryer for a continuous process is similar to the design encountered in fluid systems. The structure of the bed (Figure 7) is usually a cylindrical column with an overflow discharge pipe for a dried solids outlet, a perforated grid for gas distribution, and cyclones at the gas exit to reclaim the entrained solids.

The system described above has some unique characteristics which both enhance and deter the use of fluidized bed drying. One such characteristic is the uniformity of temperature throughout the fluidized bed dryer, except for a small region immediately above the grid[27]. In the case of heat-sensitive material the uniform bed temperature is an advantage since the temperature may easily be held below a

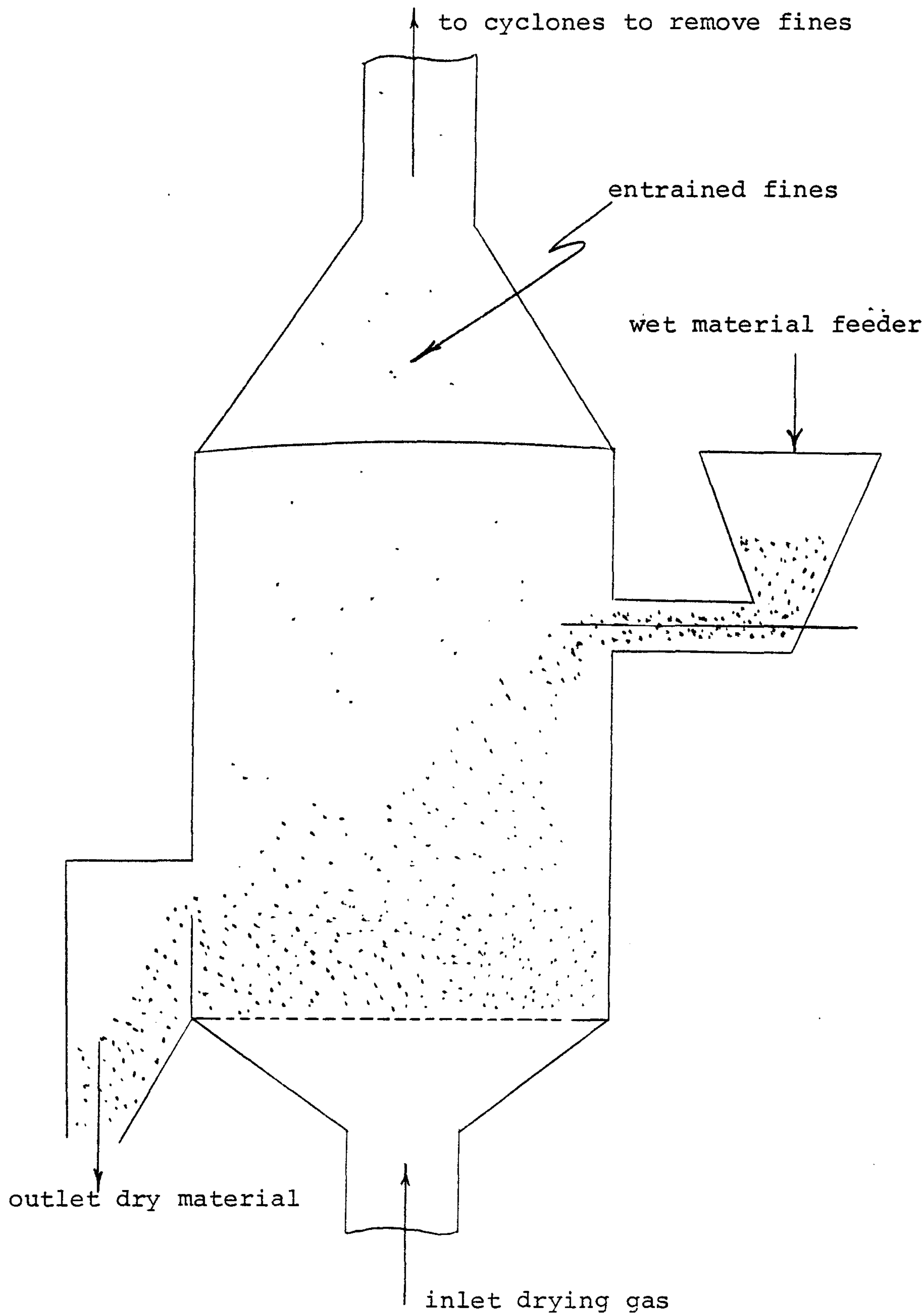

FIGURE 7. TYPICAL FLUIDIZED BED DRYER CONFIGURATION

certain value. But in all other cases the uniform temperature reduces any desirable counter-current thermal interchange effect[28]. Thus, a single fluidized bed dryer exhibits an almost ideal co-current arrangement with the temperature of the outlet gas approaching the temperature of the outlet particle stream.

Due to the thorough intermixing of solid particles within the bed the drying times of individual particles are not equal, resulting in both underdried and overdried particles in the discharge. The moisture content of the product stream must be expressed as an average moisture content. In the case of heat-sensitive materials, it may be difficult to obtain a uniform low moisture content of the outlet solids. For accurate control of product moisture content, multi-stage counter-current fluidized beds should be employed[29]. Attrition of the solid and erosion of the containing surfaces may also be caused through intermixing[30].

A fluidized bed unit is commonly selected when floor space is limited. The possibility of multiple units in a staged or stacked arrangement can offer significant savings in terms of floor area and can minimize external conveying equipment requirements.

If the drying system must be isolated from the atmosphere, the lack of rotating seals or moving parts can be quite advantageous. The lack of moving parts in a fluidized bed dryer is beneficial in troublesome maintenance areas. The fluidized bed dryer has a noticeable lack of trunnion rolls, tires, open gearing, chain drives, and moving internal and external parts of all kinds. It should also be noted that due to its compact size and relatively light weight, it is a unit which can be fabricated in alloy materials without burdensome costs[31].

B. Particle Motion

Once the bed has been sufficiently expanded, the particles tend to move as individual elements rather than in bulk. Since each particle moves independently the time of drying may vary from particle to particle. Some particles may travel directly to the exit and leave undried or may be retained for a time much longer than is required for adequate drying.

Within the dryer some of the gas moves through rapidly in the form of bubbles[32], with the conditions for heat and mass transfer unfavorable. The gas has a uniform moisture content, while the particles have different moisture contents throughout the bed.

Profiles for residence time distributions and flow characteristics have been developed and confirmed for fluidized bed operations. Weekman[33] modeled a continuous fluid bed reactor in which complete backmixing of the solids in the reactor and plug flow of the gas phase were assumed. The assumption of complete backmixing of solids has been verified for large scale commercial equipment. Plug flow of the gas phase has not been proven; in fact, this concept has been the subject of investigation. Kunii and Levenspial[34] proposed the bubbling bed model of gas flow through a fluidized bed. In their model, the gas flow is seen as uniformly sized bubbles rising through an emulsion of downward moving solids. This model has been confirmed with experimental data in batch fluidization. However, in a fluidized bed dryer the solids are fed into the bed continuously, but the assumption of plug flow of the gas phase (at high velocity) is also reasonable. The average moisture content of the reactor in the exit stream is predicted by[35]:

$$\bar{x} = \int_0^\infty X(t)\ E(t)\ dt \tag{20}$$

where

- $\bar{x}$ = average moisture content in Kg moisture/Kg dry material
- $X(t)$ = drying rate curve
- $E(t)$ = exit age distribution

For backmix flow of the solids[36]:

$$E(t) = \frac{1}{\tau}e^{-t/\tau} \tag{21}$$

where τ is the mean residence time is the dryer in sec.

C. Heat and Mass Transfer

As previously stated, drying is an operation involving simultaneous heat and mass transfer for evaporation of

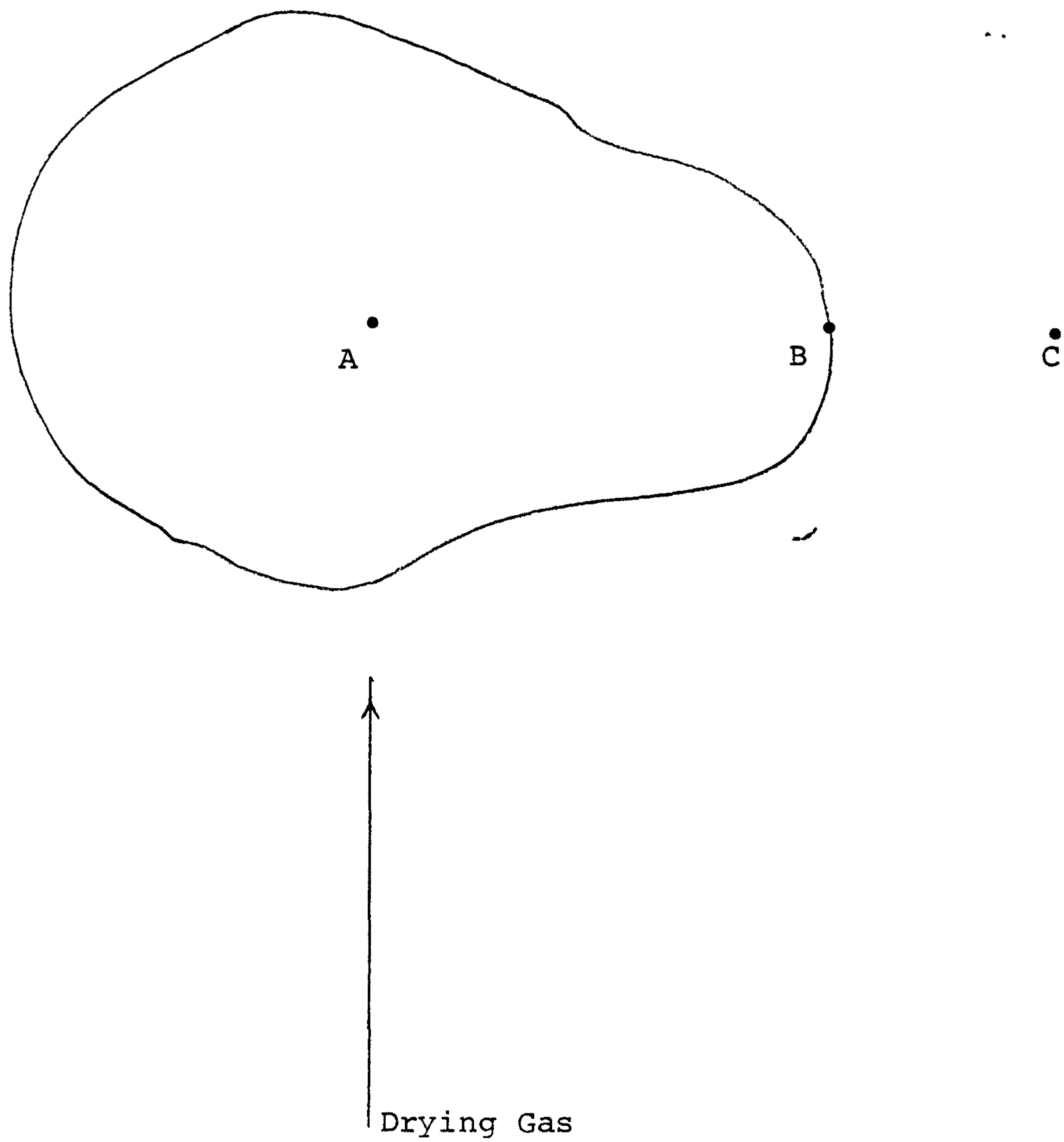

FIGURE 8. HEAT AND MASS MOVEMENT WITHIN AN INDIVIDUAL FLUIDIZED PARTICLE

moisture. In the fluidized bed a hot gas is used to enhance heat and mass transfer. Since the total surface area of the particle is available for heat and mass transfer, the maximum amount of transfer may take place at a given temperature and gas flow rate. The heat required for evaporation is supplied to the particle (Figure 8) by convection from the gas (point C) to the particle surface (point B) and then by conduction to the inside of the particle (point A). Mass in the form of moisture is transported in the opposite direction. Moisture moves from the inside of the particle (point A) to the surface of the particle (point B) as either a liquid or vapor; at the surface (point B) the moisture is evaporated, if still liquid, and then passed by convection to the drying gas (point C). The driving force for heat transfer is temperature differences. The driving force for mass transfer is given by partial pressure or concentration differences.

Extensive studies on heat and mass transfer in fluidized beds have been documented experimentally. Most studies report models for heat and mass transfer as correlations of dimensionless numbers of the form:

$$Nu = b\ Re^{m} \tag{22}$$

and

$$Sh = c\ Re^{n} \tag{23}$$

where

- Nu = Nusselt number, dimensionless
- Sh = Sherwood number, dimensionless
- b, c, m, n = experimentally determined constants

The heat transfer model is based on a heat balance around the bed[37] and includes the heat entering and exiting the expanded bed, the heat given up to the bed solids, the heat given up in heating the reactor walls, and the heat exchanged in mixing the fluid in the expanded bed. For the heat transfer model the following assumptions are made[38]:

1. The temperature change of the bed with time is essentially a first-order response.
2. Wall effects are neglected.
3. There is thorough intermixing of the solids.
4. The model does not account for a difference in aggregative or particulate fluidization.
5. The bed particles are in thermal equilibrium with the surrounding fluid.
6. The bed temperature is constant with time.
7. The exit gas temperature is equal to the temperature of the exiting particles. The solids are discharged at the upper limit of the expanded bed.
8. The gas inlet temperature is constant and the initial bed temperature is referenced to zero.

The heat balance is of the form:

$$\begin{pmatrix}\text{Heat into}\\ \text{bed}\end{pmatrix} - \begin{pmatrix}\text{Heat in}\\ \text{effluent}\end{pmatrix} = \begin{pmatrix}\text{Heat to}\\ \text{bed solids}\end{pmatrix} + \begin{pmatrix}\text{Heat in}\\ \text{mixing}\end{pmatrix} + \begin{pmatrix}\text{Heat to}\\ \text{walls}\end{pmatrix}$$

$$S_A u \rho_g C_{pg} (T_{G1} - \theta) dt = h_g A (T_{G1} - \theta) dt + C_{pg} W_g d\theta + C_{pw} W_w d\theta \tag{24}$$

where

- S_A = cross-sectional area of the equipment in m^2
- u = superficial gas velocity in cm/sec
- C_{pg} = specific heat of the gas in cal/gm - ^oC
- T_{G1} = inlet gas temperature in ^oC
- θ = gas temperature in ^oC
- t = time in seconds
- h_g = heat transfer coefficient in cal/cm^2 - sec - ^oC
- W_g = mass weight of gas in gm
- C_{pw} = the heat capacity of the wall in cal/gm - ^oC
- W_w = mass weight of the walls in gm
- A = area of particle available for drying in m^2

Utilizing equation (24) Pfafflin has derived the following correlation:

$$h_g = \frac{S_A}{A} \rho_g u C_{pg} \frac{C_{ps} W_s}{C_{ps} W_s + C_{pg} W_g + C_{pw} W_w} \tag{25}$$

The amount of heat given up by the walls has been found to be negligible and is therefore neglected. To simplify equation (23) both sides are multiplied by $(d_p \mu / kg)$ and after rearrangement produces:

$$\frac{h_g \, d_p}{K} = \frac{S_A}{A} \left(\frac{\rho_g u}{\mu}\right)\left(d_p \frac{C_{pg}\mu}{K_g}\right)\left(\frac{C_{ps} \, W_s}{C_{ps} \, W_s + C_{pg} \, W_g}\right) \tag{26}$$

where

- d_p = particle diameter in cm
- μ = gas viscosity in gm/cm-sec
- K = gas thermal conductivity in cal/cm - sec ^oC

In dimensionless forms equation (26) is

$$Nu = \frac{S_A}{A} \, Re \, Pr \left(\frac{C_{ps} \, W_s}{C_{ps} \, W_s + C_{pg} \, W_g}\right) \tag{27}$$

where

- Nu = Nusselt number, dimensionless
- Re = Reynolds number, dimensionless
- Pr = Prandtl number, dimensionless

In air fluidized systems the term $C_{pg} \, W_g$ may be neglected since it is much smaller than $C_{ps} \, W_s$ (for air systems Pr = 0.72 is also a common assumption[39]), which further simplifies equation (27) to:

$$Nu = \frac{S_A}{A} \, Re \, Pr \tag{28}$$

Numerous correlations have been reported from experimental data. The following are some of the better documented correlations:

Richardson and Ayers[40]	$Nu = 0.054\ Re^{1.28}$	(29)
Kettering, Manderfield, Smith[41]	$Nu = 0.0125\ Re^{1.30}$	(30)
Kunii and Levenspial[42]	$Nu = 0.3\ Re^{1.30}$	(31)
Lemlich and Caldas[43]	$Nu = 0.055\ Re$	(32)
Juvenland, Deinken, Dougherty[44]	$Nu = 0.063\ Re^{1.17}$	(33)

The results varied from investigator to investigator, partly because of the difficulty in measuring gas and solid temperatures. The use of thermocouples was often employed and it was often difficult to determine whether the temperature measured was the gas temperature, the solids temperature, or some intermediate temperature. Juvenland, et al[45], attempted to avoid the confusion in temperature reading by installing an optical pyrometer for the solids temperature and a high-speed thermocouple probe placed downstream from the bed to measure gas temperature.

A mass transfer model may be developed using a similar approach as that of the heat transfer model. Again some initial assumptions must be made in addition to the assumptions made for the heat transfer model. These assumptions are[46]:

1. The diffusion rate within the particle is not high.
2. The materials are nonreactive.
3. The concentration of particles within the gas is

constant throughout the bed.

4. The change in concentration with time in the exit solid is a first-order response.
5. The moisture content of the exit stream is the same as the majority of the bed with the exit stream at the top of the bed.
6. The moisture content of the incoming solids is constant with time.

The mass balance will be of the form:

$$\begin{pmatrix}\text{Mass into}\\ \text{system}\end{pmatrix} - \begin{pmatrix}\text{Mass out}\\ \text{of system}\end{pmatrix} = \begin{pmatrix}\text{Mass transferred}\\ \text{from bed}\end{pmatrix} + \begin{pmatrix}\text{Mass transferred}\\ \text{in fluid mixing}\end{pmatrix}$$

$$S_A\ u(x_1 - x_2)dt = K\ A\ (x_1 - x_2)dt + V_g\ dx \tag{34}$$

where

- x_1 = initial moisture content in g/cm^3
- x_2 = final moisture content in g/cm^3
- x = moisture content
- V_g = volume of gas in cm^3

Equation (34) may be modified by taking into account the change in the bed solid volume:

$$S_A\ u(x_1 - x_2)\ dt = V_s\ dx + V_g\ dx \tag{35}$$

where V_s is the solid volume in cm^3. Using equations (34) and (35) Kettering has derived the following correlation:

$$Sh = \frac{S_A}{A} \, Re \; Sc \, \frac{V_s}{V_s + V_g} \tag{36}$$

where Sh is the Sherwood number and Sc is the Schmidt number. Correlations similar to those developed for heat transfer (equations (29-33)) have also been developed for mass transfer:

Romankov and Lepilkin[47]:

$$Sh = 46.25 \times 10^{-6} \, Re^{1.67} \tag{37}$$

Richardson and Szekely[48]:

$$Sh = 0.374 \, Re^{1.18} \quad \text{for } .1 < Re < 15 \tag{38}$$

Richardson and Szekely:

$$Sh = 2.01 \, Re^{.5} \quad \text{for } 15 < Re < 250 \tag{39}$$

As discussed in the drying section there are two distinct regions of drying rates: the constant rate and the falling rate. During the constant rate period, surface moisture is being evaporated. Here the rate of drying is independent of the moisture level and is defined by the heat transfer equation as[49]:

$$\dot{m} = \frac{dm}{dt} = -h_g A(T_G - T_i)/\lambda_i \tag{40}$$

where

- $\dot{m}$ = rate of evaporation of liquid from the solid surface, kg/hr
- A = area available for drying, m^2
- T_i = interfacial temperature, K
- T_G = gas temperature, K
- λ_i = heat of vaporization at T_i, kcal/kg

If the particles are of constant size (spheres with radius r in m), the area available for heat transfer for a single particle is:

$$A = 4\pi\ r^2 \tag{41}$$

then the mass of liquid in the particle is defined by:

$$m = \frac{4}{3}\pi\ r^3\ x\rho_s \tag{42}$$

where ρ_s is the dry density of the particles in kg/m^3.

In differential terms, with respect to time, equation (42) becomes:

$$\frac{dm}{dt} = \frac{4}{3}\pi\ r^3\ \rho_s\ \frac{dx}{dt} \tag{43}$$

Substitution of equation (43) into the heat transfer equation (40) solving for $\frac{dx}{dt}$ and integrating yields for the constant rate period:

$$x = x_1 - \frac{3}{r\,\rho_s\,\lambda_i} h_g(T_G - T_i)t \qquad (44)$$

where x_1 is the initial moisture content in kg moisture/kg dry solid.

During the falling rate period diffusion of moisture to the particle surface controls the rate of evaporation. of liquid is described by[50]:

$$\frac{\partial x}{\partial t} = \mathcal{D}_V \frac{\partial^2 x}{\partial z^2} \qquad (45)$$

where $\mathcal{D}_V$ is diffusivity in cm^2/sec and z is the direction of diffusivity in cm. For mass transfer through a sphere Carslow and Jaeger suggest[51]:

$$x = \frac{6x_1}{\pi^2} \exp(-\pi^2\ \mathcal{D}_V t/r^2) \qquad (46)$$

The point at which the drying rate changes from the constant rate to falling rate is known as the critical moisture content, x_c. From equation (44) the drying time necessary to reach the critical moisture content may be determined:

$$t_c = (x_1 - x_c)\ r\rho_s\,\lambda_i/(3\ h_g(\bar{T}_G - T_{L2})) \qquad (47)$$

where

- t_c is the time at the critical moisture content, sec.

- $\bar{T}_G$ = the log-mean temperature of the gas in K
- T_{L2} = the exit solids temperature in K

An overall equation for calculation of exit moisture content may be written by substituting equations (44), (46) and (47) into (20) and integrating:

$$x_2 = x_1(1 - e^{-t_c/\tau})$$

$$- \frac{3\tau}{r\,\rho_p\lambda_i} h_g(\bar{T}_G - T_{L2})(1 - (\frac{t_c}{\tau} + 1)e^{-t_c/\tau})$$

$$+ \frac{6x_1}{\pi^2\,\tau\left(\dfrac{\pi^2\,\mathcal{D}_V}{r^2} + \dfrac{1}{\tau}\right)} \exp\left[\left(\frac{-\pi^2\,\mathcal{D}_V}{r^2} - \frac{1}{\tau}\right) t_c\right] \qquad (48)$$

D. Material and Energy Balance

The envelope around which the material and energy balance is performed is shown in Figure 9. For this discussion several assumptions are made: the drying gas will be air, the moisture to be removed is water, and there are no entrained particles. A water balance on the system yields:

$$G_s(y_2 - y_1) = L_s(x_1 - x_2) \qquad (49)$$

where

- G_s = the air flow rate, Kg dry air/hr

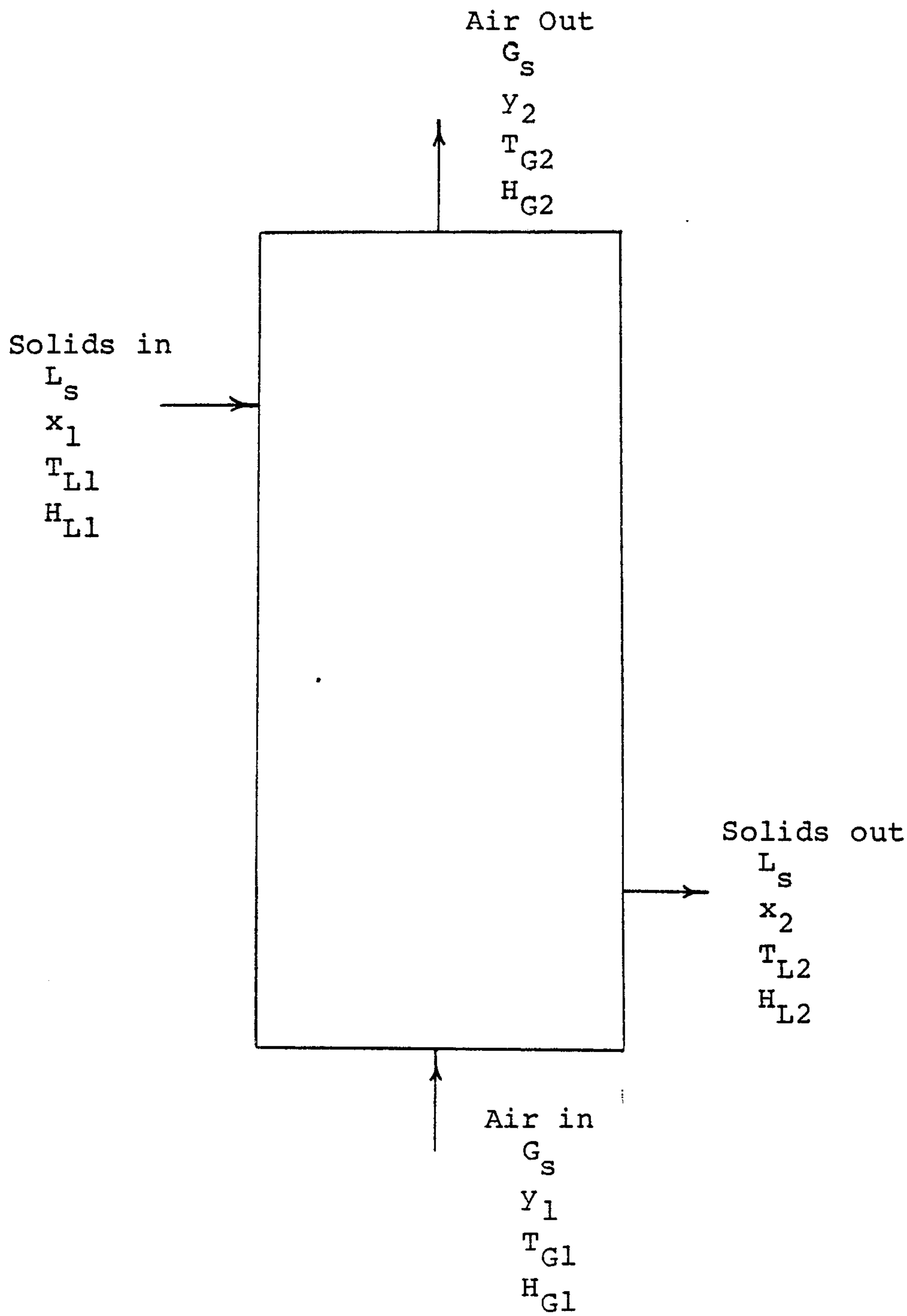

FIGURE 9. MATERIAL AND ENERGY BALANCE DIAGRAM

- y_1 = inlet moisture content (air), kg H_2O/kg dry air
- y_2 = outlet moisture content (air), kg H_2O/kg dry air
- L_s = solid flow rate kg dry/hr
- x_1 = inlet solid moisture content kg H_2O/kg dry solid
- x_2 = outlet solid moisture content kg H_2O/kg dry solid

The energy (enthalpy) balance yields

$$L_s(H_{L1} - H_{L2}) = G_s(H_{G2} - H_{G1}) + Q \tag{50}$$

where

- H_{L1} = the enthalpy of inlet solid at T_{L1}, cal/kg dry solid
- H_{L2} = the enthalpy of outlet solid at T_{L2}, cal/kg dry solid
- H_{G2} = the enthalpy of outlet gas at T_{G2}, cal/kg dry gas
- H_{G1} = the enthalpy of inlet gas at T_{G1}, cal/kg dry gas
- Q = heat loss from dryer, cal/hr

With the enthalpy of a wet solid described by[52]:

$$H_L = C_{Ps}(T_L - T_o) + x\, C_{PL}(T_L - T_o) + \Delta H_A \tag{51}$$

where

- C_{Ps} = heat capacity of dry solid, cal/kg K
- C_{PL} = heat capacity of dry gas, cal/kg K

- T_o = reference temperature, K
- ΔH_A = integral heat of wetting at T_o, cal/kg dry solid

and for a wet gas[53]:

$$H_G = C_{PG}(T_G - T_o) + y\ C_{PL}(T_G - T_o) + \lambda_o \tag{52}$$

where

- C_{PG} = heat capacity of dry gas, cal/kg K
- λ_o = latent heat of vaporization at T_o, cal/kg H_2O

In the system considered the heat of wetting will be assumed to be negligible[54].

E. Summary

The fundamental concepts of fluidized bed drying have been presented. From the equations derived for fluidized bed drying a mathematical model is presented in the next section. The important factors which make fluid bed drying attractive include the highest possible degree of contact between the solids and drying gases, very high heat and mass transfer rates, and the extremely good solids mixing within the bed.

V. MODEL DEVELOPMENT

From the previous discussion a mathematical model is developed to simulate drying in a fluidized bed dryer. This section also outlines the procedure to be used for further investigation of fluidized bed dryers. The computer model developed is in English units due to the availability of supportive data in this unit system.

A. First, several physical properties for drying must be determined from literature or experimental calculations:

1) of the material to be dried:

- Diameter of the particle (d_p, ft)
- Particle surface area (S_A, ft)
- Heat capacity (C_{ps}, BTU/lb-$^{\circ}$F)
- Density (ρ_p, lb/ft^3)
- Incipient fluidization velocity (u_{mf}, ft/sec)

2) of the gas:

- Thermal conductivity (K, BTU/ft-sec $^{\circ}$F)
- Heat capacity (C_{pg}, BTU/lb-$^{\circ}$F)
- Density (ρ_g, lb/ft^3)
- Viscosity (μ, lb/ft-sec)

3) of the moisture to be evaporated:

- Heat capacity as a liquid (C_{pLl}, BTU/lb-$^{\circ}$F)
- Heat capacity as a vapor (C_{pLg}, BTU/lb-$^{\circ}$F)

4) from the drying rate curve determine:

- Critical moisture content (x_c, g/cm^3)
- Diffusivity ($\mathcal{D}_v$, cm^2/sec)

B. Determine the initial operating conditions for the dryer:

1) given data:

- Solid inlet moisture content (x_1, g/cm^3)
- Solid inlet temperature (T_{L1}, ^oF)

2) assumed data:

- Inlet air temperature (T_{G1}, ^oF)
- Absolute humidity (y_1, lb H_2O/lb BDA)
- Mass velocity of inlet air (G, lb/sec)
- Solid (dry) flow rate (L_s, lb dry/sec)
- Solid outlet moisture content (x_2, g/cm^3)

C. With the aid of the material balance (Equation (49)), determine the outlet air humidity (in lb H_2O/lb BDA):

$$y_2 = \frac{L_s}{G_s}(x_1 - x_2) + y_1 \tag{53}$$

where

$$G_s = \frac{G}{1 + y_1} \tag{54}$$

Using the psychometric chart (Figure 10), the outlet air and outlet solid temperatures are determined. The adiabatic saturation curve enables one to calculate the temperatures. The adiabatic saturation curve used is located at the

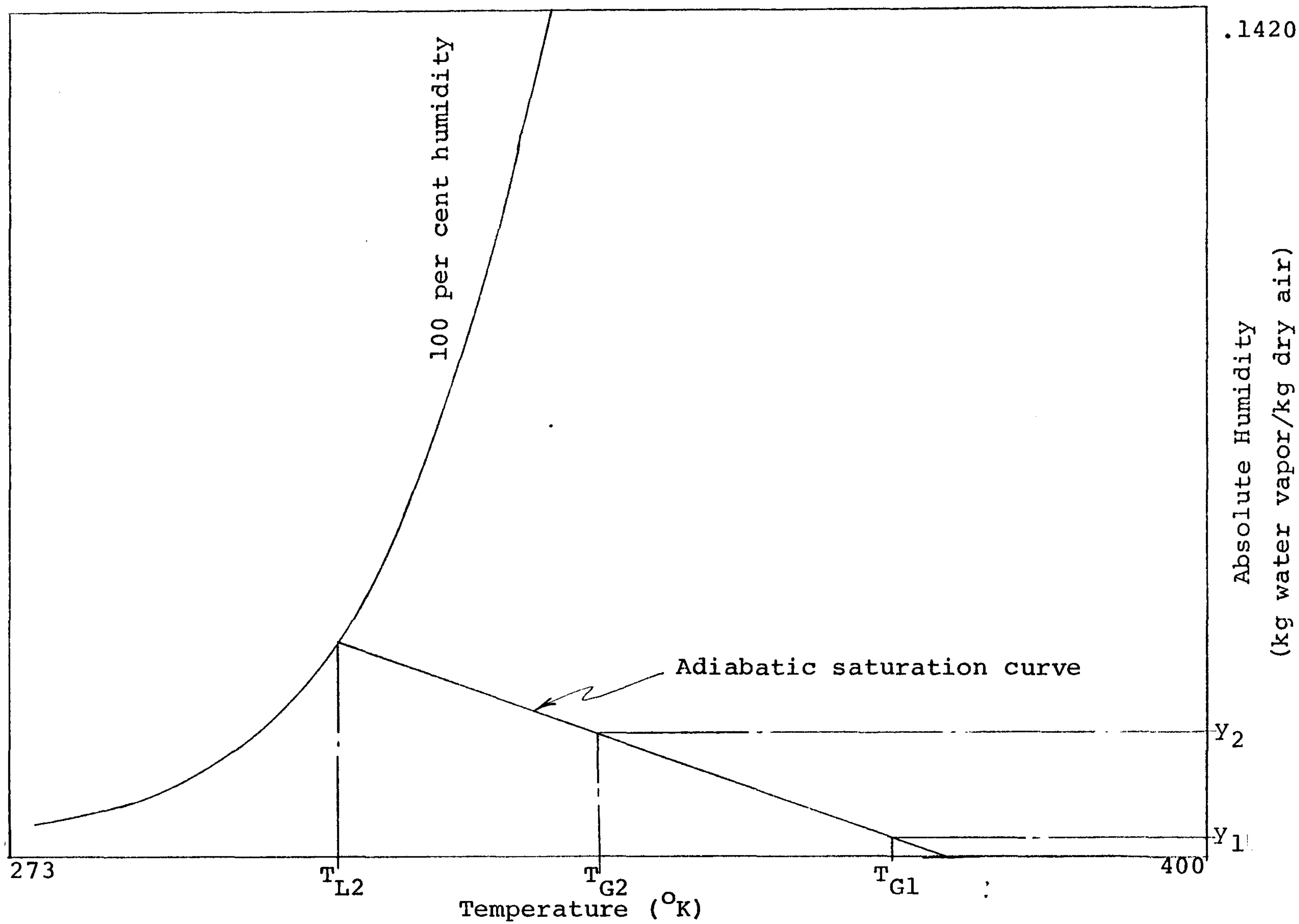

FIGURE 10. THE PSYCHOMETRIC CHART AS USED FOR DETERMINING OPERATING TEMPERATURES

intersection of y_1 and T_{G1}. The outlet gas temperature is located from the intersection of y_2 and the adiabatic saturation curve. Finally, the outlet solid temperature is found from the intersection of the 100 per cent humidity curve and the adiabatic saturation curve.

D. Since the reading of the psychometric chart with any accuracy is difficult, the outlet air temperature estimated from the psychometric chart was verified based on the heat requirements to the system. The heat balance of the system was made for the heat given up by the air and available for heat transfer, the heat required to evaporate the moisture, and the heat lost to the surroundings.

Due to the lack of adequate information concerning heat loss from the system, the heat loss was estimated as a percentage of heat produced based on the air flow rate and the bed configuration[55]. A computer program HEAT (Appendix C) was developed to calculate the heat balance for five outlet temperatures (two below and two above the temperature estimated from the psychometric chart) and generate the per cent heat loss. A least-squares of per cent heat loss versus air outlet temperature was used to determine the air outlet temperature for a given heat loss percentage.

The following equation sequence is used in the program HEAT:

a) Determine heat available for moisture evaporation (with Q in BTU/sec):

$$Q = G_s(H_{G1} - H'_{G2}) \tag{55}$$

where H_{G1} in BTU/lb BDA, the inlet air stream enthalpy, is determined from:

$$H_{G1} = (C_{pg} + C_{pL}\ y_1)(T_{G1} - T_o) + y_1\ \lambda_o \tag{56}$$

and H'_{G2} in BTU/lb BDA, the pseudo outlet air enthalpy or the enthalpy if no moisture was picked up:

$$H'_{G2} = (C_{pg} + C_{PL}\ y_3)(T_{G2} - T_o) + y_1\ \lambda_o \tag{57}$$

b) Determine the heat required for drying:

- for evaporation of water (BTU/hr):

$$Q_1 = L_s(x_1 - x_2)\ \lambda_o \tag{58}$$

- for heating of water (BTU/hr):

$$Q_2 = L_s(x_1 - x_2)(C_{pL1})(T_{G2} - T_o) \tag{59}$$

- for heating of the solid (BTU/hr):

$$Q_3 = L_s(C_{ps})(T_{L2} - T_o) \tag{60}$$

Thus the total heat required by the dryer for evaporation is (in BTU/hr):

$$Q_4 = Q_1 + Q_2 + Q_3 \tag{61}$$

c) The amount of heat loss may then be determined from (with Q_5 in BTU/hr)

$$Q_5 = Q - Q_4 \tag{62}$$

d) The per cent heat loss is then:

$$Q_6 = Q_5/Q \tag{63}$$

E. Next a heat and mass transfer model must be selected. Unfortunately, no data were available for an accurate estimation of diffusivity of water in ABS, which therefore made the selection of a mass transfer model impossible. The heat transfer model was selected based on given operating conditions of the Monsanto dryer. The model developed by Juvenland, Deinken, and Dougherty (Equation (33)) gave the best results. The method Juvenland, et al employed, as explained earlier, supports the selection of this model. The model was slightly modified (see Appendix A) to fit the data.

F. Finally, all of the previous findings are incorporated into one final program, FLUID (Appendix D). This program incorporates the heat balance, the heat transfer model, as well as calculations for fluidization velocity, bed voidage, and expanded bed height.

The following equation sequence is used in the program FLUID:

a) A heat balance similar to that described in the HEAT program section.

b) Calculation of physical constants from theoretical equations:

1) Density of air (with ρ_G in lb/ft^3)

$$\rho_g = 1/((.703\ \bar{T}_G + 336)(1/29 + (y_1 + y_2)/36)) \qquad (64)$$

2) Thermal conductivity in BTU/ft-sec-^oF:

$$K = \mu(C_{pg} + 2.48/28.8) \qquad (65)$$

where μ (viscosity) is obtained from charts.

c) Calculate fluidization velocity in ft/sec:

$$u = (G)/(S_A \cdot \rho_s) \qquad (66)$$

d) Determine the Reynolds number:

$$Re = (d_p \cdot u \cdot \rho_s)/\mu \qquad (67)$$

e) Calculate the heat transfer coefficient in BTU/ft^2-sec-^oF:

$$h_g = 0.0114(K/d_p)(Re)^{1.17} \qquad (68)$$

f) Calculate the Archimedes number:

$$Ar = \frac{g(d_p)^3\ (\rho_s - \rho_g)}{(\mu/\rho_g)^2\ (\rho_g)} \qquad (69)$$

g) Determine the bed voidage:

$$\varepsilon = Ar^{-0.21} (18\ Re + .35\ Re^2)^{0.21} \tag{70}$$

h) Determine the bed height in ft:

$$h = h_o/(1 - \varepsilon) \tag{71}$$

i) Finally, all units are converted into S.I. and printed.

G. Program modification for simulation at different operating parameters may be easily accomplished by changing a few lines within the computer programs. For the program HEAT, lines 60, 70, 80, 520 and 530 should be considered for modification. In the program FLUID, lines 120, 130, 140, 1030, 1380, 1390 and 1400 may require change. The function of the data in these lines should be easily recognized. If a different system or particle is used, more lines may require modification.

VI. DISCUSSION OF RESULTS

The programs developed in the previous sections were run for eight different data sets as summarized in Table I. Before the programs were run, several initial assumptions about the Monsanto system and ABS particles had to be made.

The preliminary assumptions that were made were based on data provided by the Monsanto Company (Table II). The data provided were for a steady-state operation; thus the computer program written is for a steady-state operation. Areas of concern were the particle characteristics, the dryer structure, operating limitations and possible operating points.

For the particles a diameter had to be estimated. The harmonic mean diameter was used for the diameter (see Appendix A for calculation). As mentioned previously, no data were available for diffusivity and therefore no mass transfer calculations can be made. From the data on density and packed bed height, the grid surface area was estimated (Appendix A) since the specifications for the dryer's internal design were not available.

The temperature limitations are a result of the fact that if these temperatures are exceeded, the polymer begins to char. Recall that the inlet temperature may be slightly higher than the limiting temperature due to

TABLE I

SUMMARY OF CONDITIONS FOR PROGRAM RUNS

Data Set	Solids Flow Rate kg/sec	Solid Moisture Content Inlet kg H_2O/kg dry solid	Solid Moisture Content Outlet kg H_2O/kg dry solid	Comments
1	1.27	0.5624	0.0446	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
2	1.27	0.5624	0.02041	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
3	1.27	0.4705	0.0446	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
4	1.27	0.6667	0.0446	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
5	1.58	0.5625	0.0446	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
6	1.89	0.5625	0.0446	3 Gas Flow Rates 2 Air Humidities 3 Air Temperatures
7	1.58	0.5625	0.0446	6 Gas Flow Rates based on ΔT of Data Set 1 2 Air Humidities 3 Air Temperatures
8	1.89	0.5625	0.0446	6 Gas Flow Rates based on ΔT of Data Set 1 2 Air Humidities 3 Air Temperatures

TABLE II

SUMMARY OF MONSANTO OPERATING CONDITIONS

ABS DATA: SIEVE ANALYSIS

Mesh	% Retained
10	40
20	82
30	92
60	97
80	99+

SPECIFIC HEAT = 0.50 BTU/lb-^{o}F (504 cal/kg- K)

DENSITY = 21.3 lb/ft^3 (.341 gm/cm^3)

STREAM TO FLUID BED DRYER: (per hour)	6453 lb (2927 kg) polymer solid
	3557 lb (1613 kg) H_2O
	72 lb (33 kg) hydrocarbons
	@ 100^{o}F (37.8 ^{o}C)
PRIMARY STREAM FROM FLUID BED: (per hour)	6006 lb (2724 kg) polymer solid
	180 lb (81.6 kg) H_2O
	60 lb (27 kg) hydrocarbons
AIR STREAM AFTER CYCLONES: (per hour)	447 lb (203 kg) polymer solid
	44 lb (20 kg) H_2O
	4 lb (2 kg) hydrocarbons
	@ 92 ^{o}F (33 ^{o}C)

TABLE II (continued)

MISCELLANEOUS DRYER INFORMATION:

- INLET FLOW RATE = 44000 SCFM (20.76 m^3/sec)
- MINIMUM FLUIDIZATION VELOCITY = 250-300 ft/min (1.27-1.52 m/sec)
- MAXIMUM AIR INLET TEMPERATURE = 257 $^{\circ}F$ (398 K)
- MAXIMUM AIR OUTLET TEMPERATURE = 176 $^{\circ}F$ (353 K)
- FOR CURRENT FLOW RATES DRYER HAS A PACKED HEIGHT = 1.5 ft (.46 m)

ideal mixing. Limitations on air flow rates must be considered to insure fluidization at lower flow rates and to keep the particles entrained by the gas to a minimum at higher flow rates. For calculation purposes the bed height was estimated from equation (18), since experimental data over a range of gas flow rates were not available. The overhead gas stream was assumed to have no particles entrained since no method of estimation is available.

The program was run for two sets of inlet air humidities: one (.001 kg/kg) for winter operation with the other (.0214 kg/kg) for summer operation. Both estimations are based on average weather data for the Cincinnati area provided by the National Weather Bureau.

Heat loss estimations were based on per cent of heat input. The estimations were based on recommendations made by Carslaw[56]. For the three air flow rates (19.8, 20.8, and 21.7 m^3/sec) used, 2.0, 2.5, and 3.0 per cent heat loss estimations were used.

In summary some fundamental assumptions had to be made to test the developed model. The effect that the assumptions will have on the accuracy of the model cannot be determined.

The computer runs of the program FLUID yielded ample data for changes in operating parameters and the effect on the final product and fluidization quality. The data were compiled in six graphs to demonstrate the effect of air flow rate on bed height (Figures 11-16) with inlet

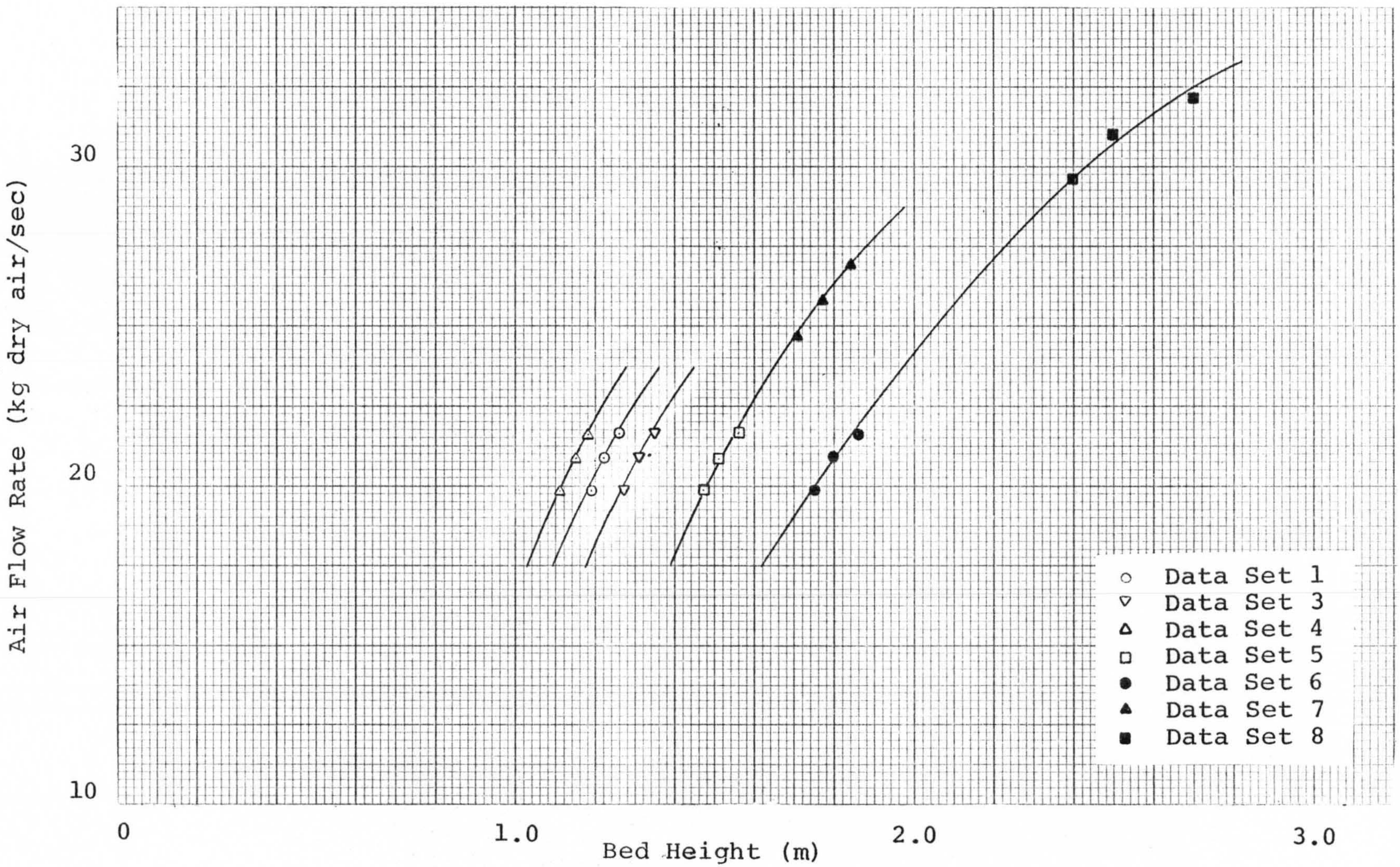

FIGURE 11. COMPARISON OF DATA SETS WITH
Y_1 = .001 kg/kg AND T_{G1} = 377.4 ^{O}K

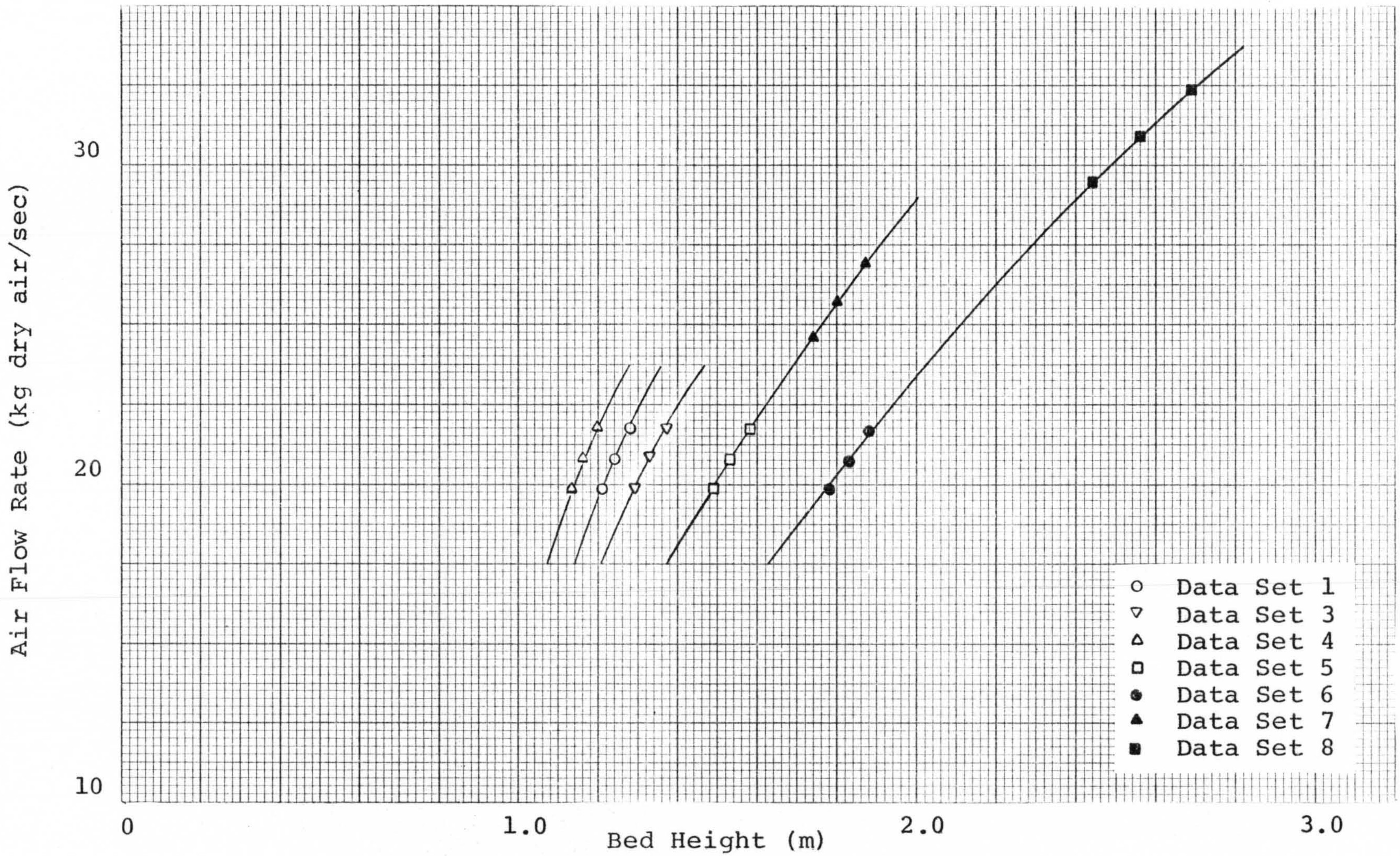

FIGURE 12. COMPARISON OF DATA SETS WITH Y_1 = .001 kg/kg AND T_{G1} = 388.6 $^{\circ}$K

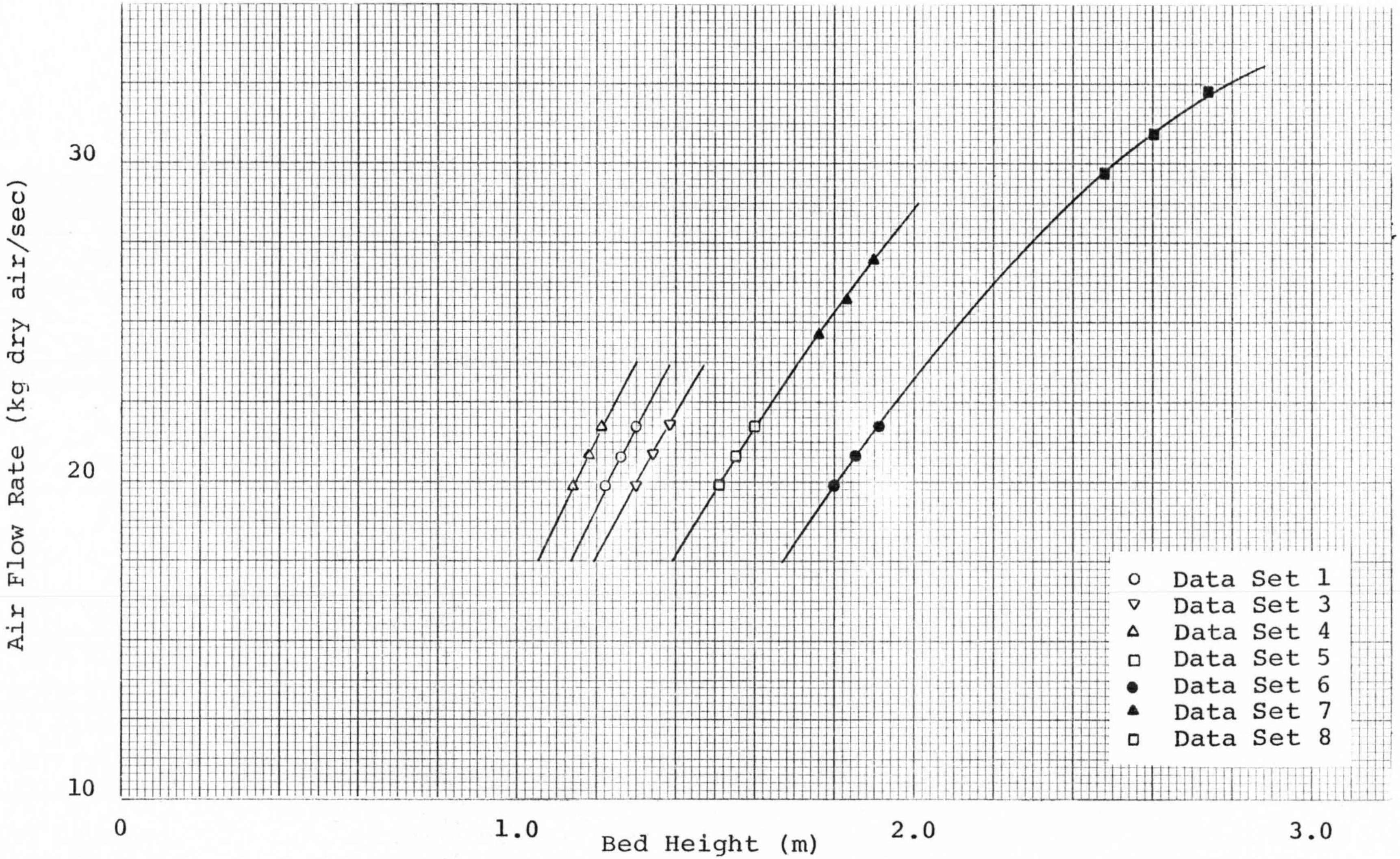

FIGURE 13. COMPARISON OF DATA SETS WITH
Y_1 = .001 kg/kg AND T_{G1} = 399.7

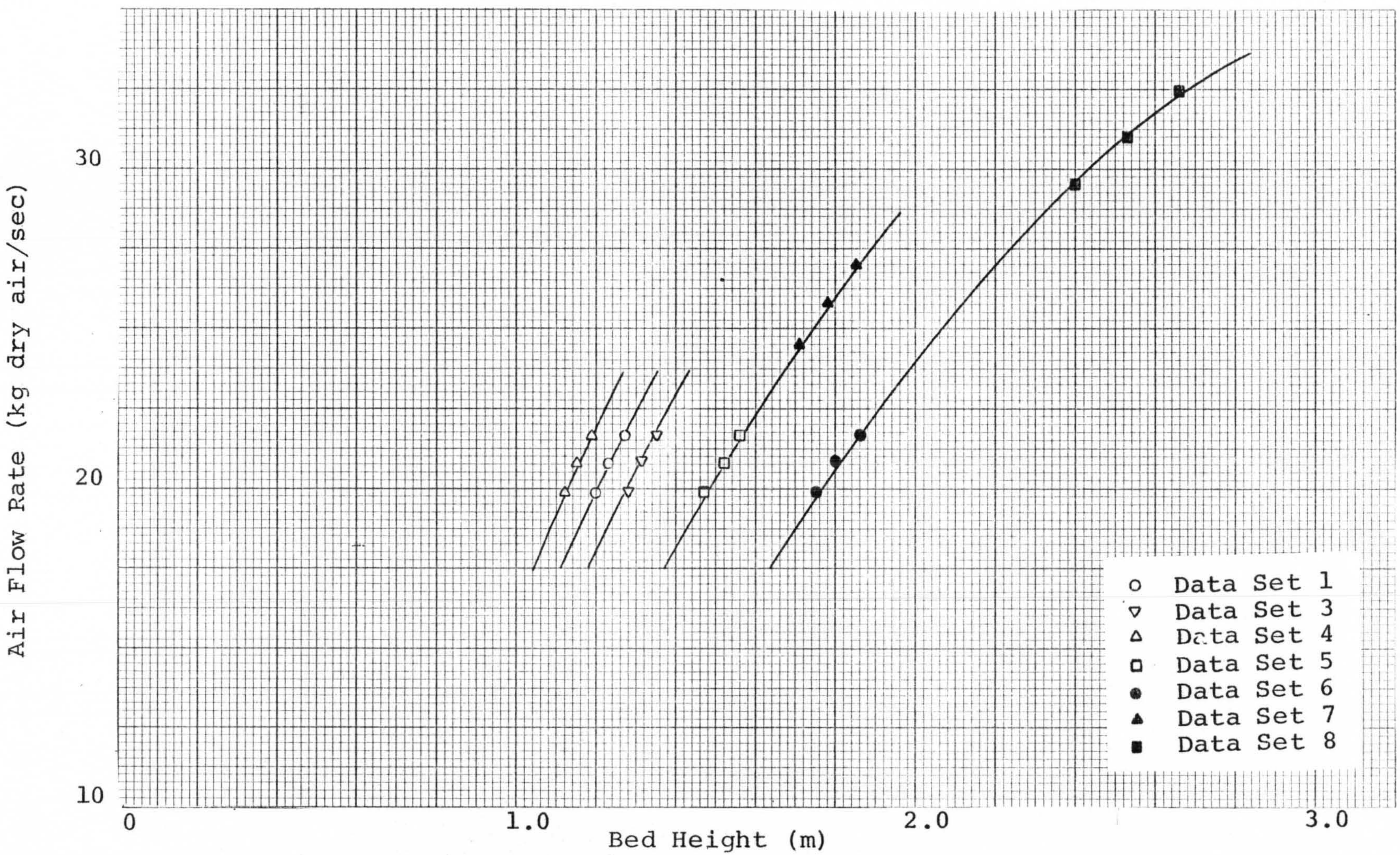

FIGURE 14. COMPARISON OF DATA SETS WITH
Y_1 = .0214 kg/kg AND T_{G1} = 377.4

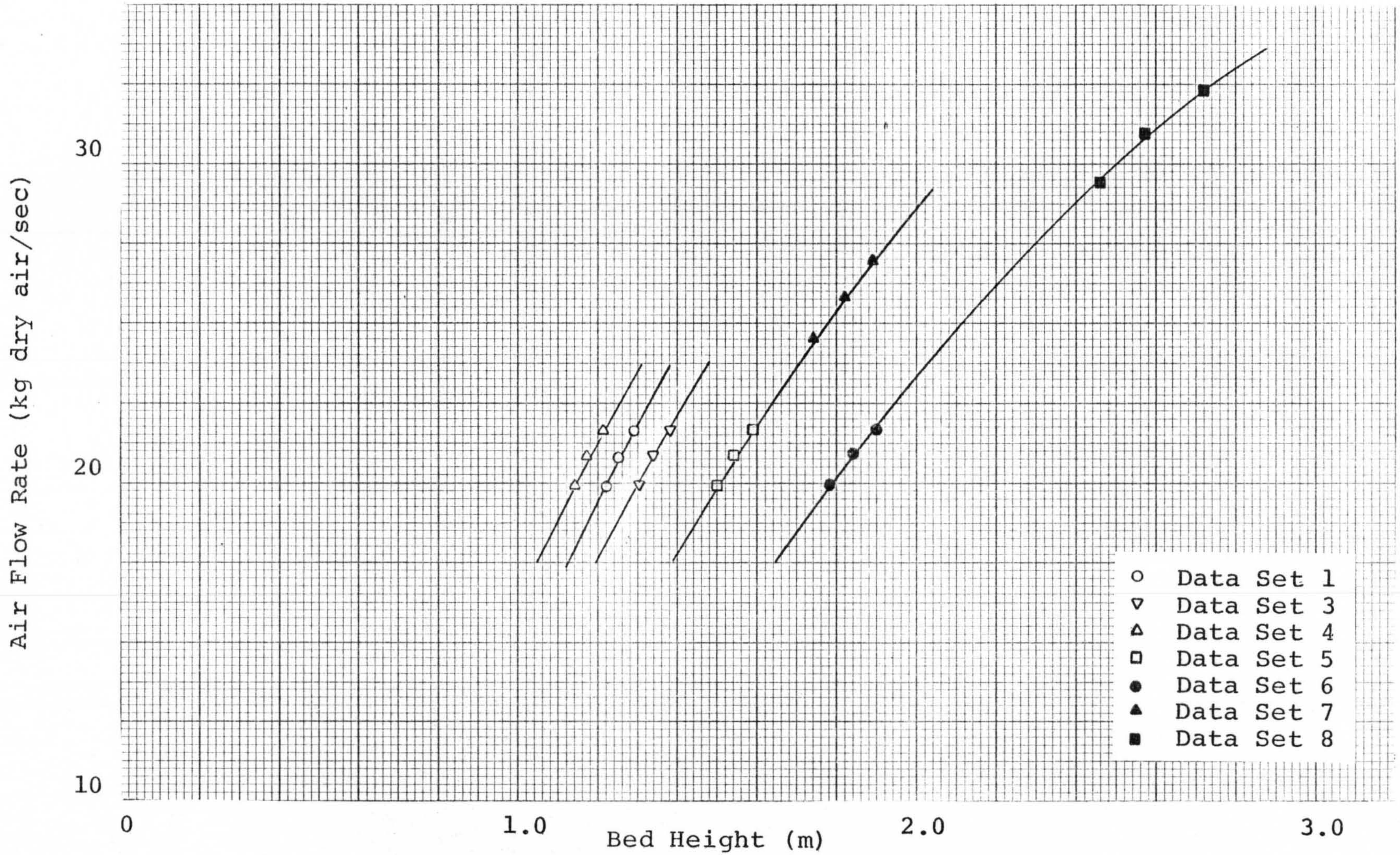

FIGURE 15. COMPARISON OF DATA SETS WITH $Y_1 = .0214$ kg/kg AND $T_{G1} = 388.6\ ^{o}K$

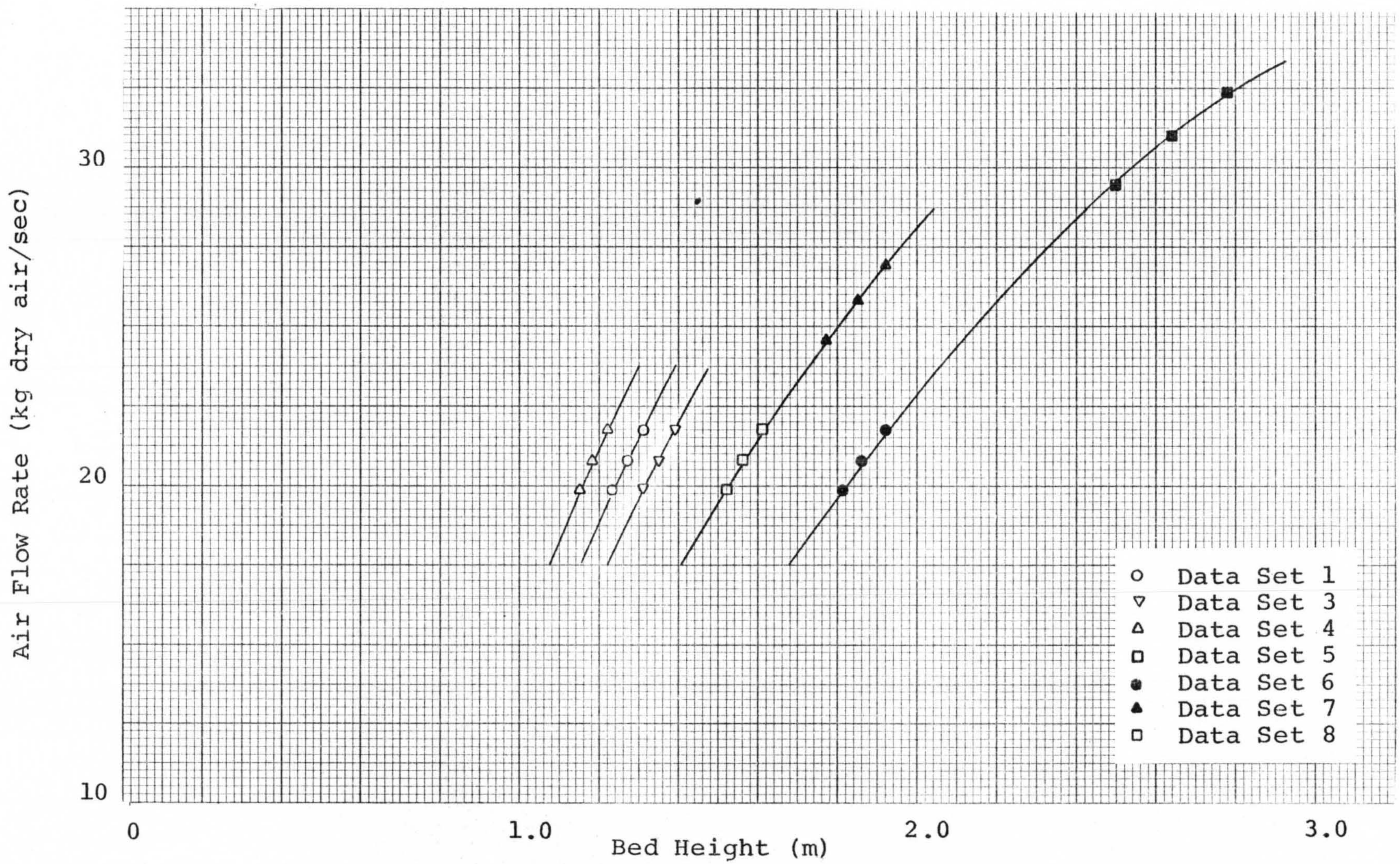

FIGURE 16. COMPARISON OF DATA SETS WITH Y_1 = .0214 kg/kg AND T_{G1} = 399.7 ^{o}K

humidity and temperature constant.

The upper limit for bed height is 5 ft (1.52 m) which was selected since the dryer is 10 ft (3.04 m) tall. This was chosen since, in general, fluidized beds are designed with 50 per cent disengaging space-only experimentation will justify this assumption[57].

The first data set represents the current efficiency of Monsanto's dryer. Run 11 most nearly matches Monsanto's dryer. The other data sets represent possible load upsets and increasing loads to the dryer.

As expected, an increase in temperature increases the fluid velocity which also increases the bed height. An increase in the humidity increases the fluid velocity since, as humidity increases, the humid volume increases - thus the density of the air decreases. The effect of the humidity change on bed height is not substantial whereas temperature change and gas velocity do have a substantial effect on the bed height. With bed height a definite limitation, and temperature of inlet air the major driving force of drying, the air flow rate should be adjusted for maximum bed height at the maximum temperature of inlet air possible.

The change of height in the bed increases at a higher rate when the gas velocity changes occur at higher air flow rates with smaller increases in bed heights at lower flow rates. The curve that forms at high air flow rates may be seen on Figure 11. Data sets 5 and 7 and data sets 6 and 8 both curve at high flow rates while being linear at lower flow rates. Data set combination 5 and 7 and 6 and 8 are continuous lines because all operating conditions are the same except for the increase in air flow rates.

At the current operating conditions the dryer does not meet design specifications for exit moisture content. The desired exit moisture content of the solid is 2 per cent with current operating conditions yielding a 4 per cent moisture content. Data set 2 represents a 2 per cent exit moisture content. The difference between data set 2 (2 per cent) and data set 1 (4 per cent) is very slight (see Table III - for this reason data set 2 was not included in Figures 11 to 16). Therefore, the Monsanto dryer can reach the desired moisture content with an increase in residence time of the particle, since the change in the other parameters is negligible.

Data set 5 is identical to data set 1 except that the solids input rate was increased to 12500 lb/hr (1.58 kg/sec). The bed height increased as expected since the packed bed height is increased. The air flow rate with an increase in solid flow rate is no longer adequate for fluidization, since the bed voidage is less than .65 in all cases [58]. In data set 7 the gas flow was increased such that the change in air temperature would be the same as data sets 5 and 7, the expanded bed height is over the operation bed height; thus entrainment of the polymer

TABLE III

VARIATIONS OF EXPANDED BED HEIGHT (in meters)

BETWEEN RUNS AND DATA SETS

Run	Data Set 1	2	3	4	5	6	7	8
1	1.19	1.19	1.27	1.11	1.47	1.75	1.71	2.39
2	1.21	1.21	1.29	1.13	1.49	1.78	1.74	2.44
3	1.22	1.22	1.30	1.14	1.51	1.80	1.76	2.48
4	1.20	1.20	1.28	1.12	1.47	1.75	1.71	2.40
5	1.22	1.21	1.30	1.14	1.50	1.78	1.74	2.46
6	1.23	1.23	1.31	1.15	1.52	1.81	1.77	2.50
7	1.22	1.23	1.31	1.15	1.51	1.80	1.77	2.50
8	1.24	1.24	1.33	1.16	1.53	1.83	1.80	2.56
9	1.26	1.26	1.34	1.18	1.55	1.85	1.83	2.60
10	1.23	1.23	1.31	1.15	1.52	1.80	1.78	2.53
11	1.25	1.25	1.33	1.17	1.54	1.84	1.82	2.59
12	1.27	1.27	1.35	1.18	1.56	1.86	1.85	2.64
13	1.26	1.26	1.35	1.18	1.56	1.86	1.84	2.63
14	1.28	1.28	1.37	1.20	1.58	1.88	1.87	2.69
15	1.30	1.30	1.38	1.21	1.60	1.91	1.90	2.74
16	1.27	1.27	1.35	1.19	1.56	1.86	1.85	2.66
17	1.29	1.29	1.38	1.21	1.59	1.90	1.89	2.72
18	1.31	1.31	1.39	1.22	1.61	1.92	1.92	2.78

particles is likely.

For data set 6 the solid flow rate was further increased to 15000 lb/hr (1.89 kg/sec). Data set 6 was developed similar to data set 5, and data set 8 was developed similar to data set 7. Again at the increased solid input, the expanded bed height was greater than the operational limit. The higher flow rates of solids show that Monsanto's dryer, as is, will not be able to adequately dry the ABS polymer at increased solid input without substantial entrainment since the bed height is greater than 1.52 m.

A change in the inlet solid moisture content will result in a change in the bed height. Data set 3 represents a decrease in inlet moisture content to 32 per cent. The expanded bed height is greater than that of the higher moisture content since the incoming particle is now lighter. Also since less heat is required for evaporation, the outlet air will be hotter; thus the density of the air will be smaller and result in a higher superficial fluid velocity. Data set 4 represents an increase in the inlet moisture content of 40 per cent. As expected, the expanded bed height decreases due to the increased weight of the particle and the lower superficial fluid velocity resulting from air with a higher density.

The possibility of lowering the inlet moisture content may enable the Monsanto dryer to meet specifications. The most economical manner to obtain the decrease would be to utilize a flash dryer. In a flash dryer, the material becomes entrained within an air stream. The flash dryer is extremely successful at drying unbound moisture from solids. The flash dryer could supply the fluid bed dryer with particles slightly drier; thus the particles could be dried to within specifications.

In summary, to ensure a workable mathematical model of a fluidized bed dryer, an experimental study must be performed. Drying rate curves must be generated for all run conditions for a model of diffusivity. A mass transfer model may be selected with the experimental data supported or rewitten. The heat transfer model may also be proved or disproved. Problems of entrainment can only be solved through the experimental trials. To date, an adequate study such as this has not been published, and the design of fluid bed dryers continues to be a series of trial-and-error calculations.

VII. CONCLUSIONS

The following is a list of conclusions from this study:

1. The main variable parameters are the expanded bed height and inlet gas temperature.

2. An accurate mathematical model of a fluid bed dryer will be difficult due to the nature of fluidization and the phenomenon of drying.

3. An increased residence time or the lowering of the inlet particle moisture content may enable the ABS to be dried to within specifications.

4. The Monsanto dryer will not be able to handle increased solid flow rates without a significant amount of particle entrainment.

VIII. RECOMMENDATIONS

The following is a list of recommendations regarding future investigations of fluidized bed dryers:

1. Perform an experimental study involving fluidized bed drying to supply needed data on mass transfer, heat transfer, heat losses, expanded bed height, entrainment, and the effects of changing operating conditions.

2. Investigate the possibility of a dynamic mathematical model of fluidized bed drying.

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APPENDIX A

SAMPLE CALCULATION

SAMPLE CALCULATION

1. TYLER SCREEN ANALYSIS FOR THE DETERMINATION OF THE WEIGHT MEAN DIAMETER

Screen Meshes	d_p (in)	$\bar{d}_n$ (in)	$\Delta\phi_n$	$\Delta\phi_n \bar{d}_n$
3/6	.265-.132	.1985	.26	.05161
6/10	.132-.0661	.09905	.22	.02179
10/20	.0661-.0331	.0496	.23	.01141
20/35	.0331-.0165	.0248	.11	.002728
35/60	.0165-.0098	.01315	.1	.001315
60/100	.0098-.0059	.00785	.066	.000518
		TOTALS	0.986	0.098937

From equation (3)

$$\bar{d}_w = \frac{\sum \Delta\phi_n \, d_n}{\sum \Delta\phi_n} = \frac{.08937}{.986} = 0.09064 \text{ in} = 0.0075532 \text{ ft}$$

(0.0023 m)

$$S_A = \frac{6}{\rho_s \, \bar{d}_w} = 37.29 \text{ ft}^2/\text{lb} \ (7.63 \text{ m}^2/\text{kg})$$

2. DETERMINATION OF HEAT TRANSFER EQUATION

Assume the equation is similar to equation (3):

$$Nu = a(Re)^{1.17}$$

a. Determine the required heat transfer coefficient for Data Set 1, Run 11:

$$h_g = \frac{Q}{\bar{T}_G} \; \frac{S_A}{A}$$

$$= \left(\frac{3669461.589 \text{ BTU/hr}}{95.83 \ ^{\circ}\text{F}}\right)\left(\frac{113.1 \text{ ft}^2}{240657.5 \text{ ft}^2}\right)$$

$$= 18.00 \text{ BTU/hr} \cdot {}^{\circ}\text{F} \ (9.50 \text{J/s} - \text{K})$$

b. Calculate the Nusselt Number:

$$Re = \frac{(18.00 \text{ BTU/hr} \cdot {}^{\circ}\text{F})(0.00755 \text{ ft})}{(0.0172 \text{ BTU/hr} \cdot \text{ft} \cdot {}^{\circ}\text{F})}$$

$$= 7.90$$

c. Calculate the Reynolds Number:

$$Re = \frac{(0.00755 \text{ ft})(551.2 \text{ ft/min})(60 \text{ min/hr})(0.0566 \text{ lb/ft}^3)}{(0.0527 \text{ lb/ft} \cdot \text{hr})}$$

$$= 268.2$$

d. Determine the constant a:

$$a = \frac{7.90}{(268.2)^{1.17}}$$

$$= 0.0114$$

3. The following is a demonstration of the program FLUID using Data Set 1, Run 11. The calculations are done in the order discussed in Section V, Model Development.

A. 1) d_p = 0.007553 ft

S_A = 240658 ft^2

C_{ps} = .5 BTU/lb

ρ_s = 21.3 lb/ft^3

u_{mf} = 200 ft/sec

2) K = 0.0173 BTU/ft - sec ^oF

C_{pg} = 0.242 BTU/lb - ^oF

ρ_g = 0.0686 lb/ft^3

μ = 0.0527 lb/ft - hr

3) C_{PL1} = 1.0 BTU/lb - ^oF

C_{PLg} = 0.45 BTU/lb - ^oF

B. 1) x_1 = 0.5624 lb H_2O/lb BDS

T_{L1} = 100 ^oF

2) T_{G1} = 240 ^oF

y_1 = 0.0214 lb H_2O/lb BDA

G = 44000 scfm

L_s = 6453 lb dry/hr

x_2 = 0.0446 lb H_2O/lb BDS

C. $$G_s = \frac{211765 \text{ lb/hr}}{(1 + .0214)} = 207328 \text{ lb BDA/hr} \qquad (54)$$

$$Y_2 = \frac{6453 \text{ lb BDS}}{207328 \text{ lb BDA}} (.5624 - .0446) \frac{\text{lb } H_2O}{\text{lb BDS}} \qquad (53)$$

$$+ 0.0214 \text{ lb } H_2O\text{/lb BDA}$$

$$= 0.0375 \text{ lb } H_2O\text{/lb BDA}$$

D. a) $$Q = 207328 \text{ lb BDA/hr}(74.94 - 57.24) \cdot \text{BTU/lb BDA} \qquad (55)$$

$$Q = 3669500 \text{ BTU/hr (1075 kJ/sec)}$$

b) $$Q_1 = 6453 \text{ lb BDS}(.5624 - .0446) \cdot \text{lb } H_2O\text{/lb BDS (1037.1 BTU/lb } H_2O) \qquad (58)$$

$$= 3465000 \text{ BTU/hr}$$

$$Q_2 = (6453 \frac{\text{lb BDS}}{\text{hr}})(.5624 - .0446) \frac{\text{lb } H_2O}{\text{lb BDS}} \qquad (59)$$

$$\cdot (.45 \frac{\text{BTU}}{\text{lb } H_2O})(169.1 - 100)\ ^oF$$

$$= 103900 \text{ BTU/hr}$$

$$Q_3 = (6453 \frac{\text{lb BDS}}{\text{hr}})(.5 \frac{\text{BTU}}{\text{lb BDS}})(107 - 199)\ ^oF \qquad (60)$$

$$= 22580 \text{ BTU/hr}$$

$$Q_4 = (346500 + 103900 + 22580) \text{ BTU/hr} \tag{61}$$

$$= 3591500 \text{ BTU/hr } (1052 \text{ kJ/sec})$$

c) $$Q_5 = (3669500 - 3591500) \text{ BTU/hr} \tag{62}$$

$$= 78000 \text{ BTU/hr } (23 \text{ kJ/sec})$$

d) $$Q_6 = (78000 \text{ BTU/hr})/(3669500 \text{ BTU/hr})$$

$$= 0.0212$$

F. b) 1. $$\rho_g = 1/((.703(95.83) + 336)$$

$$\cdot (1/29 + .02946/18))$$

$$= 0.0686 \text{ lb/ft}^3$$

2. $$K = 0.0527 \text{ lb/ft-hr}(.24 + \frac{2.48}{28.8}) \frac{\text{BTU}}{\text{lb }^\circ\text{F}}$$

$$= 0.0172 \text{ BTU/hr-ft-}^\circ\text{F}$$

c) $$u = \frac{(211765 \text{ lb/hr})(1 \text{ hr/60 min})}{(201.97 \text{ ft})(0.0686 \text{ lb/ft}^3)} \tag{66}$$

$$= 254.6 \text{ ft/min } (1.3 \text{ m/sec})$$

d) $$Re = (.00755 \text{ ft})(254.6 \text{ ft/min})(60 \text{ min/hr}) \tag{67}$$

$$\cdot (.0686 \text{ lb/ft}^3)/(0.05274 \text{ lb/ft-hr})$$

$$= 150.2$$

e) $$h_g = 0.0114 \frac{(.0172 \text{ BTU/hr-ft-}^\circ\text{F})}{(0.00755 \text{ ft})} (150.2)^{1.17} \tag{68}$$

$$= 9.14 \text{ BTU/hr-}^\circ\text{F } (4.85 \text{ J/sec-K})$$

$$\text{f)}\quad Ar = \left(32.17\ \frac{\text{lb-ft}}{\text{lb-sec}}\right)(.00755\ \text{ft})^3 \tag{69}$$

$$\cdot\ (21.3 - 0.0686)\ \text{lb/ft}^3 (3600\ \text{sec/hr})^2$$

$$/\left(\frac{0.0527\ \text{lb/ft-hr}}{0.0686\ \text{lb/ft}^3}\right)^2 (.0686\ \text{lb/ft}^3)$$

$$= 94100$$

$$\text{g)}\quad \varepsilon = (94100)^{-.21}\ (18(150.2) + .35(150.2)^2)^{0.21}$$

$$= 0.63$$

$$\text{h)}\quad h = 1.5\ \text{ft}/(1 - .63)$$

$$= 4.1\ \text{ft}\ (1.25\ \text{m})$$

APPENDIX B

PROGRAM HEAT LISTING

```
LIS
HEAT

1Ø  DIM A[18],B[18],C[18],D[18]
2Ø  REM*********JIM GERSTLE********21 FEB'8Ø
3Ø  REM  25 FEB
4Ø  MAT  READ A,B,C
5Ø  N=1
6Ø  L1=6453
7Ø  X1=.5624
8Ø  X2=.Ø446
9Ø  T1=1ØØ
1ØØ  FOR G2=42ØØØ. TO 46ØØØ. STEP 2ØØØ
11Ø  G=(G2*6Ø)/((1/28.8)*491.7*.73Ø2)
12Ø  FOR Y1=.ØØ1 TO .Ø214 STEP .Ø2Ø4
13Ø  FOR O=1 TO 3
14Ø  G1=G/(Y1+1)
15Ø  Y2=(L1/G1)*(X1-X2)+Y1
16Ø  PRINT
17Ø  PRINT
18Ø  PRINT "     G2=",G2
19Ø  PRINT "     Y1=",Y1,"     Y2=",Y2
2ØØ  PRINT "     T3=",A[N],"     T2=",B[N]
21Ø  PRINT
22Ø  PRINT "T4","Q IN","Q REQ","Q LOSS","% LOSS"
23Ø  C[N]=C[N]-2
24Ø  FOR M=1 TO 5
25Ø  H3=(.24+.45*Y1)*(A[N]-32)+1Ø75.8*Y1
26Ø  H5=(.24+.45*Y1)*(C[N]-32)+1Ø75.8*Y1
27Ø  REM HEAT FROM AIR
28Ø  Q=G1*(H3-H5)
29Ø  REM Q TO EVAP H2O
3ØØ  Q1=L1*(X1-X2)*1Ø37.1
31Ø  REM Q TO HEAT H2O
32Ø  Q2=L1*(X1-X2)*.45*(C[N]-1ØØ)
33Ø  REM  Q TO HEAT SOLID
34Ø  Q3=L1*(.5)*(B[N]-1ØØ)
35Ø  REM TOTAL Q
36Ø  Q4=Q1+Q2+Q3
37Ø  REM HEAT LOSS
38Ø  D[N]=Q-Q4
39Ø  REM PER CENT HEAT LOSS
4ØØ  Q6=D[N]/Q*1ØØ
41Ø  PRINT C[N],Q,Q4,D[N],Q6
42Ø  C[N]=C[N]+1
43Ø  NEXT M
44Ø  N=N+1
45Ø  NEXT O
46Ø  NEXT Y1
47Ø  NEXT G2
48Ø  DATA 22Ø,24Ø,26Ø,22Ø,24Ø,26Ø,22Ø,24Ø,26Ø
49Ø  DATA 22Ø,24Ø,26Ø,22Ø,24Ø,26Ø,22Ø,24Ø,26Ø
5ØØ  DATA 89,93,96.5,1Ø4,1Ø7,1Ø9,89,93,96.5
51Ø  DATA 1Ø4,1Ø7,1Ø9,89,93,96.5,1Ø4,1Ø7,1Ø9
52Ø  DATA 147,168,188,147,17Ø,188,15Ø,171,191
53Ø  DATA 149.9,169.1,188,152.6,171.5,19Ø.6,152.9,172.1,191
54Ø  END
```

APPENDIX C

PROGRAM HEAT RUN

RUN
HEAT

G2=	42000.		
Y1=	.001	Y2=	1.75465E-02
T3=	220	T2=	89

T4	Q IN	Q REQ	Q LOSS	% LOSS
145	3.64169E+06	3.49750E+06	144189.	3.9594
146	3.59313E+06	3.49900E+06	94129.5	2.61971
147	3.54458E+06	3.50051E+06	44070.	1.24331
148	3.49602E+06	3.50201E+06	-5989.5	-.171323
149	3.44746E+06	3.50351E+06	-56048.5	-1.62579

G2=	42000.		
Y1=	.001	Y2=	1.75465E-02
T3=	240	T2=	93

T4	Q IN	Q REQ	Q LOSS	% LOSS
166	3.59313E+06	3.54198E+06	51152.	1.4236
167	3.54458E+06	3.54348E+06	1093	3.08358E-02
168	3.49602E+06	3.54499E+06	-48967.5	-1.40066
169	3.44746E+06	3.54649E+06	-99027.	-2.87246
170	3.39891E+06	3.54800E+06	-149086.	-4.38629

G2=	42000.		
Y1=	.001	Y2=	1.75465E-02
T3=	260	T2=	96.5

T4	Q IN	Q REQ	Q LOSS	% LOSS
186	3.59313E+06	3.58335E+06	9788	.272408
187	3.54458E+06	3.58485E+06	-40272.5	-1.13617
188	3.49602E+06	3.58635E+06	-90331.5	-2.58384
189	3.44747E+06	3.58786E+06	-140390.	-4.07228
190	3.39891E+06	3.58936E+06	-190449.	-5.60325

G2=	42000.		
Y1=	.0214	Y2=	3.82837E-02
T3=	220	T2=	104

T4	Q IN	Q REQ	Q LOSS	% LOSS
145	3.70521E+06	3.54590E+06	159316.	4.29978
146	3.65581E+06	3.54740E+06	108409.	2.96539
147	3.60641E+06	3.54890E+06	57503.	1.59447
148	3.55700E+06	3.55041E+06	6596	.185437
149	3.50760E+06	3.55191E+06	-44309.5	-1.26324

G2=	42000.		
Y1=	.0214	Y2=	3.82837E-02
T3=	240	T2=	107

T4	Q IN	Q REQ	Q LOSS	% LOSS
168	3.55700E+06	3.59016E+06	-33155.5	-.932119
169	3.50760E+06	3.59166E+06	-84061.5	-2.39655
170	3.45820E+06	3.59317E+06	-134968.	-3.90286
171	3.40880E+06	3.59467E+06	-185874.	-5.45279
172	3.35939E+06	3.59617E+06	-236781.	-7.04834

G2=	42000.		
Y1=	.0214	Y2=	3.82837E-02
T3=	260	T2=	109

T4	Q IN	Q REQ	Q LOSS	% LOSS
186	3.65581E+06	3.62368E+06	32131.5	.878916
187	3.60641E+06	3.62518E+06	-18774	-.520574
188	3.55700E+06	3.62668E+06	-69681.	-1.95898
189	3.50760E+06	3.62819E+06	-120586.	-3.43786
190	3.45820E+06	3.62969E+06	-171493.	-4.95904

G2=	44000.		
Y1=	.001	Y2=	1.67944E-02
T3=	220	T2=	89

T4	Q IN	Q REQ	Q LOSS	% LOSS
148	3.66250E+06	3.50201E+06	160488.	4.38193
149	3.61163E+06	3.50351E+06	108117.	2.99358
150	3.56076E+06	3.50502E+06	55745.	1.56554
151	3.50989E+06	3.50652E+06	3373	9.60998E-02 *
152	3.45903E+06	3.50802E+06	-48998.5	-1.41654

G2=	44000.		
Y1=	.001	Y2=	1.67944E-02
T3=	240	T2=	93

T4	Q IN	Q REQ	Q LOSS	% LOSS
169	3.61163E+06	3.54649E+06	65138.5	1.80358
170	3.56076E+06	3.54800E+06	12767	.358547
171	3.50989E+06	3.54950E+06	-39604.	-1.12835
172	3.45903E+06	3.55100E+06	-91976.5	-2.65903
173	3.40816E+06	3.55251E+06	-144348.	-4.23538

G2=	44000.		
Y1=	.001	Y2=	1.67944E-02
T3=	260	T2=	96.5

T4	Q IN	Q REQ	Q LOSS	% LOSS
189	3.61163E+06	3.58786E+06	23775	.65829
190	3.56076E+06	3.58936E+06	-28596	-.803086
191	3.50989E+06	3.59086E+06	-80969.5	-2.30689
192	3.45903E+06	3.59237E+06	-133340.	-3.85486
193	3.40816E+06	3.59387E+06	-185711.	-5.44903

G2=	44000.		
Y1=	.0214	Y2=	3.75163E-02
T3=	220	T2=	104

T4	Q IN	Q REQ	Q LOSS	% LOSS
149	3.67463E+06	3.55191E+06	122719.	3.33964
150	3.62287E+06	3.55341E+06	69459.5	1.91725
151	3.57112E+06	3.55492E+06	16201	.453667
152	3.51936E+06	3.55642E+06	-37058.5	-1.05299
153	3.46761E+06	3.55793E+06	-90316.5	-2.60458

G2=	44000.		
Y1=	.0214	Y2=	3.75163E-02
T3=	240	T2=	107

T4	Q IN	Q REQ	Q LOSS	% LOSS
172	3.51936E+06	3.59617E+06	-76810.	-2.1825
173	3.46761E+06	3.59768E+06	-130068.	-3.75096
174	3.41585E+06	3.59918E+06	-183328.	-5.36698
175	3.36410E+06	3.60068E+06	-236586.	-7.03267
176	3.31234E+06	3.60219E+06	-289846.	-8.75048

G2=	44000.		
Y1=	.0214	Y2=	3.75163E-02
T3=	260	T2=	109

T4	Q IN	Q REQ	Q LOSS	% LOSS
190	3.62287E+06	3.62969E+06	-6817.5	-.188179
191	3.57112E+06	3.63120E+06	-60076.	-1.68227
192	3.51936E+06	3.63270E+06	-113335.	-3.22034
193	3.46761E+06	3.63420E+06	-166593.	-4.80428
194	3.41585E+06	3.63571E+06	-219853.	-6.43625

G2= 46000.
Y1= .001 Y2= 1.61077E-02
T3= 220 T2= 89

T4	Q IN	Q REQ	Q LOSS	% LOSS
151	3.66943E+06	3.50652E+06	162914.	4.43976
152	3.61625E+06	3.50802E+06	108229.	2.99286
153	3.56307E+06	3.50953E+06	53546.5	1.50282
154	3.50989E+06	3.51103E+06	-1138	-3.24226E-02
155	3.45671E+06	3.51254E+06	-55821.5	-1.61487

G2= 46000.
Y1= .001 Y2= 1.61077E-02
T3= 240 T2= 93

T4	Q IN	Q REQ	Q LOSS	% LOSS
171	3.66944E+06	3.54950E+06	119936.	3.26853
172	3.61625E+06	3.55100E+06	65251.5	1.80439
173	3.56307E+06	3.55251E+06	10568	.296598
174	3.50989E+06	3.55401E+06	-44115.5	-1.25689
175	3.45671E+06	3.55551E+06	-98798.5	-2.85816

G2= 46000.
Y1= .001 Y2= 1.61077E-02
T3= 260 T2= 96.5

T4	Q IN	Q REQ	Q LOSS	% LOSS
192	3.61626E+06	3.59237E+06	23888	.660573
193	3.56308E+06	3.59387E+06	-30795.5	-.864295
194	3.50990E+06	3.59537E+06	-85478.5	-2.43536
195	3.45671E+06	3.59688E+06	-140164.	-4.05483
196	3.40353E+06	3.59838E+06	-194847.	-5.72486

G2= 46000.
Y1= .0214 Y2= 3.68156E-02
T3= 220 T2= 104

T4	Q IN	Q REQ	Q LOSS	% LOSS
153	3.62523E+06	3.55793E+06	67302.	1.85649
154	3.57112E+06	3.55943E+06	11689.5	.327334
155	3.51701E+06	3.56093E+06	-43921.5	-1.24883
156	3.46290E+06	3.56244E+06	-99533.5	-2.87428
157	3.40880E+06	3.56394E+06	-155144.	-4.55128

G2= 46000.
Y1= .0214 Y2= 3.68156E-02
T3= 240 T2= 107

T4	Q IN	Q REQ	Q LOSS	% LOSS
175	3.51701E+06	3.60068E+06	-83673.	-2.37909
176	3.46290E+06	3.60219E+06	-139285.	-4.0222
177	3.40880E+06	3.60369E+06	-194895.	-5.71743
178	3.35469E+06	3.60520E+06	-250508.	-7.46742
179	3.30058E+06	3.60670E+06	-306119.	-9.2747

G2= 46000.
Y1= .0214 Y2= 3.68156E-02
T3= 260 T2= 109

T4	Q IN	Q REQ	Q LOSS	% LOSS
193	3.62523E+06	3.63420E+06	-8975	-.247571
194	3.57112E+06	3.63571E+06	-64587.5	-1.80861
195	3.51701E+06	3.63721E+06	-120198.	-3.41763
196	3.46290E+06	3.63871E+06	-175810.	-5.07697
197	3.40879E+06	3.64022E+06	-231422.	-6.78898

DONE

APPENDIX D

PROGRAM FLUID LISTING

```
LIS
FLUID

10  DIM A[18],B[18],C[18],D[18]
20  DIM E[6]
30  REM*********JIM GERSTLE********21 FEB'80
40  REM
50  REM 25 FEB,1 MAR
60  REM 18 MAR
70  REM
80  MAT  READ A,B,C
90  MAT  READ E
100  W=1
110  N=1
120  L1=6453
130  X1=.5624
140  X2=.0446
150  T0=100
160  L0=1037.1
170  D=7.55325E-03
180  A=240658.
190  A1=201.97
200  C1=(6.9+2.084E-04*A[N]+2.429E-07*A[N]*A[N])/28.8
210  C2=1
220  C3=.5
230  T1=100
240  FOR P=1 TO 3
250  FOR Y1=.001 TO .0214 STEP .0204
260  FOR O=1 TO 3
270  G2=E[W]
280  G=(G2*60)/((1/28.8)*491.7*.7302)
290  REM CONVERT TO S. I. UNITS
300  G6=G2*4.71947E-04
310  T8=5/9*(A[N]-32)+273
320  T7=5/9*(B[N]-32)+273
330  REM CALC BONE DRY AIR IN
340  G1=G/(Y1+1)
350  REM MOISTURE CONTENT OF AIR OUT
360  Y2=(L1/G1)*(X1-X2)+Y1
370  PRINT
380  PRINT "                              RUN",N
390  PRINT
400  PRINT "      G2=";G2
410  PRINT "          (";G6;")"
420  PRINT "      Y1=";Y1,"      Y2=";Y2
430  PRINT
440  PRINT "      X1=";X1,"      X2=";X2
450  PRINT
460  PRINT "      T3=";A[N],"                            T2=";B[N]
470  PRINT "          (";T8;")","          (";T7;")"
480  PRINT
490  REM INLET AIR ENTHALPY
500  H3=(.24+.45*Y1)*(A[N]-32)+1075.8*Y1
510  REM PSEUDO-ENTHALPY AIR OUTLET
520  H5=(.24+.45*Y1)*(C[N]-32)+1075.8*Y1
530  REM HEAT FROM AIR
540  Q=G1*(H3-H5)
550  REM Q TO EVAP H2O
560  Q1=L1*(X1-X2)*1037.1
570  REM Q TO HEAT H2O
580  Q2=L1*(X1-X2)*.45*(C[N]-100)
590  REM  Q TO HEAT SOLID
600  Q3=L1*(.5)*(D[N]-100)
```

```
610  REM TOTAL Q
620  Q4=Q1+Q2+Q3
630  REM HEAT LOSS
640  D[N]=Q-Q4
650  REM PER CENT HEAT LOSS
660  Q6=D[N]/Q*100
670  REM LOG-MEAN TEMPERATURE
680  T5=((C[N]-B[N])-(A[N]-T1))/(LOG((C[N]-B[N])/(A[N]-T1)))
690  REM DENSITY OF AIR
700  Y3=(Y1+Y2)/2
710  D1=1/((.703*T5+336)*(1/29+Y3/18))
720  IF A[N] >= 221 THEN 750
730  U=.021
740  GOTO 840
750  IF A[N] >= 241 THEN 780
760  U=.0218
770  GOTO 840
780  IF A[N] >= 261 THEN 810
790  U=.022
800  GOTO 840
810  PRINT
820  PRINT "      INLET AIR TEMPERTURE TOO HIGH"
830  GOTO 1410
840  U=U*2.4191
850  REM THERMAL CONDUCTIVITY
860  K=U*(C1+2.48/28.8)
870  REM  CALC. FLUIDIZATION VELOCITY
880  U1=(G/60)/(A1*D1)
890  REM CALC REYNOLDS NUMBER
900  R1=(D*U1*D1*60)/U
910  REM HEAT TRANSFER COEFFICIENT CALC
920  H=.0114*(K/D)*(R1)↑1.17
930  REM AMOUNT HEAT TRANSFERED
940  Q7=H*(A/A1)*T5
950  REM PER CENT OF HEAT TRANSFERED
960  Q8=Q7/Q
970  REM CALC ARCHIMEDES NUMBER
980  D2=21.3
990  A2=((32.17)*(3600↑2)*(D↑3)*(D2-D1))/((U/D1)↑2*D1)
1000  REM BED VOIDAGE
1010  E=(A2↑(-.21))*(18*R1+.36*(R1↑2))↑.21
1020  REM EXPANDED BED HEIGHT
1030  B0=1.875
1040  B1=B0/(1-E)
1050  REM CONVERT TO S. I. UNITS
1060  T9=5/9*(C[N]-32)+273
1070  Z1=Q*2.9306E-04
1080  Z2=Q4*2.9306E-04
1090  Z3=D[N]*2.9306E-04
1100  Z4=U1*.00508
```

```
1110  Z5=H*.5275
1120  Z6=Q7*2.9306E-Ø4
1130  Z7=BØ*.3Ø48
1140  Z8=B1*.3Ø48
1150  PRINT
1160  PRINT "T4","Q IN","Q REQ","Q LOSS","% LOSS"
1170  PRINT C[N],Q,Q4,D[N],Q6
1180  PRINT "(";T9;")","(";Z1;")","(";Z2;")","(";Z3;")"
1190  PRINT
12ØØ  PRINT "FLUID VEL","REYNOLDS NO","H T COEFF","HEAT TRANS",
121Ø  PRINT U1,R1,H,Q7,Q8
122Ø  PRINT "(";Z4;")"," ","(";Z5;")","(";Z6;")"
123Ø  PRINT
124Ø  PRINT "ARCHIMEDES NO","BED VOIDAGE","PACKED HEIGHT","EXPANDED
125Ø  PRINT A2,E,BØ,B1
126Ø  PRINT " "," ","(";Z7;")","(";Z8;")"
127Ø  PRINT
128Ø  PRINT "*******************************************************
129Ø  N=N+1
13ØØ  NEXT O
131Ø  W=W+1
132Ø  NEXT Y1
133Ø  NEXT P
134Ø  DATA 22Ø,24Ø,26Ø,22Ø,24Ø,26Ø,22Ø,24Ø,26Ø
135Ø  DATA 22Ø,24Ø,26Ø,22Ø,24Ø,26Ø,22Ø,24Ø,26Ø
136Ø  DATA 89,93,96.5,1Ø4,1Ø7,1Ø9,89,93,96.5
137Ø  DATA 1Ø4,1Ø7,1Ø9,89,93,96.5,1Ø4,1Ø7,1Ø9
138Ø  DATA 146.4,165.3,184.2,146.7,165.8,184.6,149.7,168.6,187.5
139Ø  DATA 149.9,169.1,188,152.6,171.5,19Ø.6,152.9,172.1,191
14ØØ  DATA 522ØØ.,52ØØØ.,545ØØ.,546ØØ.,57ØØØ.,571ØØ.
141Ø  END
```

APPENDIX E

PROGRAM FLUID RUNS

TABLE IV

INITIAL CONDITIONS FOR DATA SET 1

$L = 1.27$ Kg/sec $\quad$ $T_1 = 310.8^oK$ $\quad$ $x_1 = 0.5624$ Kg/Kg

$L_1 = 0.813$ Kg/sec $\quad$ $x_2 = 0.0446$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	377.4	337.0	336.6	40.8
		306.9	388.6	348.0	347.0	41.6
		308.8	399.7	360.0	357.6	42.1
	0.0214	313.0	377.4	337.0	336.7	40.7
		314.7	388.6	350.0	347.3	41.3
		315.8	399.7	360.0	357.8	41.9
20.76	0.001	304.7	377.4	338.0	338.4	39.0
		306.9	388.6	350.0	348.9	39.7
		308.8	399.7	361.0	359.4	40.3
	0.0214	313.0	377.4	339.0	388.5	38.9
		314.7	388.6	352.0	349.2	39.4
		315.8	399.7	362.0	359.7	40.0
21.71	0.001	304.7	377.4	340.0	340.0	37.4
		306.9	388.6	351.0	350.5	38.1
		308.8	399.6	363.0	361.1	38.6
	0.0214	313.0	377.4	341.0	340.2	37.2
		314.7	388.6	354.0	350.8	37.8
		315.8	399.6	363.0	361.3	38.4

TABLE V

INITIAL CONDITIONS FOR DATA SET 2

L = 1.27 Kg/sec

L_1 = 0.813 Kg/sec

T_1 = 310.8 ^oK

x_1 = 0.5624 Kg/Kg

x_2 = 0.02041 Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	377.4	335.0	334.7	42.7
		306.9	388.6	347.0	345.2	43.4
		308.8	399.7	357.0	355.6	44.1
	0.0214	313.0	377.4	334.0	334.9	42.5
		314.7	388.6	349.0	345.7	42.9
		315.8	399.7	359.0	356.0	43.7
20.76	0.001	304.7	377.4	337.0	336.6	40.8
		306.9	388.6	349.0	347.0	41.6
		308.8	399.7	360.0	357.6	42.1
	0.0214	313.0	377.4	337.0	336.8	40.6
		314.7	388.6	350.0	347.4	41.2
		315.8	399.7	360.0	357.8	41.9
21.71	0.001	304.7	377.4	339.0	338.3	39.1
		306.9	388.6	350.0	348.8	39.8
		308.8	399.7	361.0	359.3	40.4
	0.0214	313.0	377.4	339.0	338.5	38.9
		314.7	388.6	352.0	349.3	39.3
		315.8	399.7	362.0	359.6	40.1

TABLE VI

INITIAL CONDITIONS FOR DATA SET 3

$L = 1.27$ Kg/sec

$L_1 = 0.864$ Kg/sec

$T_1 = 310.8\ ^oK$

$x_1 = 0.4705$ Kg/Kg

$x_2 = 0.0446$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	377.4	340.0	341.7	35.7
		306.9	388.6	353.0	352.2	36.4
		308.8	399.7	365.0	362.7	37.0
	0.0214	313.0	377.4	343.0	341.8	35.6
		314.7	388.6	356.0	352.6	36.0
		315.8	399.7	366.0	363.0	36.7
20.76	0.001	304.7	377.4	342.0	343.3	34.1
		306.9	388.6	355.0	353.8	34.8
		308.8	399.7	367.0	364.4	35.3
	0.0214	313.0	377.4	345.0	343.3	34.1
		314.7	388.6	357.0	354.2	34.4
		315.8	399.7	367.0	364.6	35.1
21.71	0.001	304.7	377.4	344.0	344.7	32.7
		306.9	388.6	356.0	355.3	33.3
		308.8	399.7	368.0	365.9	33.8
	0.0214	313.0	377.4	347.0	344.8	32.6
		314.7	388.6	356.0	355.3	33.3
		315.8	399.7	369.0	366.1	33.6

TABLE VII

INITIAL CONDITIONS FOR DATA SET 4

$L = 1.27$ Kg/sec　　$T_1 = 310.8\ ^oK$　　$x_1 = 0.667$ Kg/Kg

$L_1 = 0.762$ Kg/sec　　　　$x_2 = 0.0446$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	337.4	332.0	331.5	45.9
		306.9	388.6	344.0	341.9	46.7
		308.8	399.7	355.0	352.4	47.3
	0.0214	313.0	377.4	334.0	331.9	45.5
		314.7	388.6	347.0	342.7	45.9
		315.8	399.7	356.0	352.8	46.9
20.76	0.001	304.7	377.4	334.0	333.6	43.8
		306.9	388.6	346.0	344.0	44.6
		308.8	399.7	357.0	354.6	45.1
	0.214	313.0	377.4	336.0	333.9	43.5
		314.7	388.6	349.0	344.7	43.9
		315.8	399.7	358.0	354.9	44.8
21.71	0.001	304.7	377.4	336.0	335.4	42.0
		306.9	388.6	347.0	345.9	42.7
		308.8	399.6	359.0	356.3	43.4
	0.0214	313.0	377.4	338.0	335.8	41.6
		314.7	388.6	351.0	346.6	42.0
		315.8	399.6	360.0	356.9	42.8

TABLE VIII

INITIAL CONDITIONS FOR DATA SET 5

$L = 1.58$ Kg/sec

$L_1 = 1.01$ Kg/sec

$T_1 = 310.8\ ^oK$

$x_1 = 0.5625$ Kg/Kg

$x_2 = 0.04493$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperature (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	377.4	327.0	327.2	50.2
		306.9	388.6	339.0	337.4	51.2
		308.8	399.7	350.0	347.8	51.9
	0.0214	313.0	377.4	328.0	327.3	50.1
		314.7	388.6	342.0	338.0	50.6
		315.8	399.7	352.0	348.3	51.4
20.76	0.001	304.7	377.4	330.0	329.4	48.0
		306.9	388.6	341.0	339.7	48.9
		308.8	399.7	352.0	350.0	49.7
	0.0214	313.0	377.4	332.0	329.7	47.7
		314.7	388.6	344.0	340.2	48.4
		315.8	399.7	354.0	350.5	49.2
21.71	0.001	304.7	377.4	332.0	331.4	46.0
		306.9	388.6	343.0	341.8	46.8
		308.8	399.6	354.0	352.2	47.5
	0.0214	313.0	377.4	335.0	331.8	45.6
		314.7	388.6	346.0	342.2	46.4
		315.8	399.6	356.0	352.6	47.1

TABLE IX

INITIAL CONDITIONS FOR DATA SET 6

$L = 1.89$ Kg/sec

$L_1 = 1.21$ Kg/sec

$T_1 = 310.8\ ^oK$

$x_1 = 0.5625$ Kg/Kg

$x_2 = 0.04493$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperature (^oK) T_2	T_3	T'_4	T_4	ΔT_{air}
19.82	0.001	304.7	377.4	317.0	317.6	59.8
		306.9	388.6	329.0	327.7	60.9
		308.8	399.7	338.0	337.8	61.9
	0.0214	313.0	377.4	319.0	317.8	59.6
		314.7	388.6	333.0	328.3	60.3
		315.8	399.7	343.0	338.5	61.2
20.76	0.001	304.7	377.4	319.0	320.2	57.2
		306.9	388.6	331.0	330.4	58.2
		308.8	399.7	343.0	340.6	59.1
	0.0214	313.0	377.4	322.0	320.4	57.0
		314.7	388.6	335.0	330.9	57.7
		315.8	399.7	345.0	341.1	58.6
21.71	0.001	304.7	377.4	322.0	322.6	54.8
		306.9	388.6	334.0	332.8	55.8
		308.8	399.6	346.0	343.1	56.6
	0.0214	313.0	377.4	324.0	322.8	54.6
		314.7	388.6	338.0	333.4	55.2
		315.8	399.6	348.0	343.7	56.0

TABLE X

INITIAL CONDITIONS FOR DATA SET 7

$L = 1.58$ Kg/sec

$L_1 = 1.01$ Kg/sec

$T_1 = 310.8\ ^{o}K$

$x_1 = 0.5625$ Kg/Kg

$x_2 = 0.04493$ Kg/Kg

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^{o}K) T_2	T_3	T'_4	T_4	ΔT_{air}
24.64	0.001	304.7	377.4	337.0	336.6	40.8
		306.9	388.6	348.0	347.0	41.6
		308.8	399.7	360.0	357.6	42.1
24.54	0.0214	313.0	377.4	337.0	336.7	40.7
		314.7	388.6	350.0	347.3	41.3
		315.8	399.7	360.0	357.8	41.9
25.72	0.001	304.7	377.4	338.0	338.4	39.0
		306.9	388.6	350.0	348.9	39.7
		308.8	399.7	361.0	359.4	40.3
25.77	0.0214	313.0	377.4	339.0	338.5	38.9
		314.7	388.6	352.0	349.2	39.4
		315.8	399.7	362.0	359.7	40.0
26.90	0.001	304.7	377.4	340.0	340.0	37.4
		306.9	388.6	351.0	350.5	38.1
		308.8	399.6	363.0	361.1	38.6
26.95	0.0214	313.0	377.4	341.0	340.2	37.2
		314.7	388.6	354.0	350.8	37.8
		315.8	399.6	363.0	361.3	38.4

TABLE XI

INITIAL CONDITIONS FOR DATA SET 8

$L = 1.89$ Kg/sec

$L_1 = 1.21$ Kg/sec

$T_1 = 310.8\ ^oK$

$x_1 = 0.5625$

$x_2 = 0.4493$

Gas Flow Rate m^2/sec	Inlet Air Humidity Kg/Kg	Temperatures (^oK)				
		T_2	T_3	T'_4	T_4	ΔT_{air}
29.54	0.001	304.7	377.4	337.0	336.6	40.8
		306.9	388.6	348.0	347.0	41.6
		308.8	399.7	360.0	357.6	42.1
29.45	0.0214	313.0	377.4	337.0	336.7	40.7
		314.7	388.6	350.0	347.3	41.3
		315.8	399.7	360.0	357.8	41.9
30.86	0.001	304.7	377.4	338.0	338.4	39.0
		306.9	388.6	350.0	348.9	39.7
		308.8	399.7	361.0	359.4	40.3
30.91	0.0214	313.0	377.4	339.0	338.5	38.9
		314.7	388.6	352.0	349.2	39.4
		315.8	399.7	362.0	359.7	40.0
32.28	0.001	304.7	377.4	340.0	340.0	37.4
		306.9	388.6	351.0	350.5	38.1
		308.8	399.6	363.0	361.1	38.6
32.32	0.0214	313.0	377.4	341.0	340.2	37.2
		314.7	388.6	354.0	350.8	37.8
		315.8	399.6	363.0	361.3	38.4

TABLE XII

THE UNITS FOR THE PROGRAM FLUID RUNS

G2 = scfm
(scms)

Y1 = lb H_2O/lb BDA

X1 = lb H_2O/lb BDA

T3 = ^oF
(K)

Q IN = BTU/hr
(kJ/sec)

Q LOSS = BTU/hr
(kJ/sec)

H T COEFF = BTU/hr-^oF
(J/sec-K)

PACKED HEIGHT = ft
(m)

Y2 = lb H_2O/lb BDA

X2 = lb H_2O/lb dry solid

T2 = ^oF
(K)

T4 = ^oF
(K)

Q REQ = BTU/hr
(kJ/sec)

FLUID VEL = ft/min
(m/sec)

HEAT TRANS = BTU/hr
(kJ/sec)

EXPANDED HEIGHT = ft
(m)

```
RUN
FLUID2

                    RUN          1

     G2= 42ØØØ.
        ( 19.8218     )
     Y1= .ØØ1                       Y2= 1.75465E-Ø2

     X1= .5624                      X2= .Ø446

     T3= 22Ø                        T2= 89
        ( 377.444     )                ( 3Ø4.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 146.4           3.57371E+Ø6     3.4996ØE+Ø6     741Ø6.5         2.07366
( 336.556     ) ( 1Ø47.31     ) ( 1Ø25.59     ) ( 21.7176     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 23Ø.971         148.8Ø7         8.76787         886851.         .24816
( 1.17343     )                 ( 4.625Ø5     ) ( 259.9Ø1     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 1Ø6717.         .616335         1.5             3.90965
                                ( .4572       ) ( 1.19166     )

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                    RUN          2

     G2= 42ØØØ.
        ( 19.8218     )
     Y1= .ØØ1                       Y2= 1.75465E-Ø2

     X1= .5624                      X2= .Ø446

     T3= 24Ø                        T2= 93
        ( 388.556     )                ( 3Ø6.889     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 165.3           3.62712E+Ø6     3.54Ø93E+Ø6     86194.5         2.37607
( 347.Ø56     ) ( 1Ø62.96     ) ( 1Ø37.7      ) ( 25.2602     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 23Ø.17Ø         143.347         8.71231         1.Ø6354E+Ø6     .293213
( 1.21ØØ5     )                 ( 4.59575     ) ( 311.6Ø1     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 96Ø41.9         .621354         1.5             3.96338
                                ( .4572       ) ( 1.2Ø81      )

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                    RUN          3

     G2= 42ØØØ.
        ( 19.8218     )
     Y1= .ØØ1                       Y2= 1.75465E-Ø2

     X1= .5624                      X2= .Ø446

     T3= 26Ø                        T2= 96.5
        ( 399.667     )                ( 3Ø8.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 184.2           3.66Ø53E+Ø6     3.58Ø64E+Ø6     77Ø94.5         2.71413
( 357.556     ) ( 1Ø73.62     ) ( 1Ø49.Ø4     ) ( 22.2751     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 245.5ØØ         142.643         8.69Ø79         1.246Ø5E+Ø6     .338644
( 1.24716     )                 ( 4.53861     ) ( 365.257     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 913Ø6.Ø         .6256Ø3         1.5             4.ØØØ64
                                ( .4572       ) ( 1.2218Ø     )

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                    RUN        4

     C2= 42000.
        ( 19.8218      )
     Y1= .0214                          Y2= 3.82837E-02

     X1= .5624                          X2= .0446

     T3= 220                            T2= 104
        ( 377.444      )                   ( 313   )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 146.7          3.62123E+06    3.54845E+06    72773.5        2.00964
( 336.722     ) ( 1061.24     ) ( 1039.91     ) ( 21.327      )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 234.262        148.807        8.76787        781562.        .215820
( 1.19005     )                ( 4.62505     ) ( 229.044     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 105232.        .618151        1.5            3.92825
                               ( .4572       ) ( 1.19733     )

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                    RUN        5

     C2= 42000.
        ( 19.8218      )
     Y1= .0214                          Y2= 3.82837E-02

     X1= .5624                          X2= .0446

     T3= 240                            T2= 107
        ( 388.556      )                   ( 314.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 165.8          3.66567E+06    3.58685E+06    78840.         2.15075
( 347.933     ) ( 1074.27     ) ( 1051.16     ) ( 23.1049     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 242.226        143.347        8.71231        971732.        .26508
( 1.23051     )                ( 4.59575     ) ( 284.767     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 94450.         .62374         1.5            3.9866
                               ( .4572       ) ( 1.21512     )

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                    RUN        6

     C2= 42000.
        ( 19.8218      )
     Y1= .0214                          Y2= 3.82837E-02

     X1= .5624                          X2= .0446

     T3= 260                            T2= 109
        ( 399.667      )                   ( 315.778     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 184.6          3.72497E+06    3.62157E+06    103401.        2.77591
( 357.778     ) ( 1091.64     ) ( 1061.34     ) ( 30.303      )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 250.267        142.044        8.69881        1.16606E+06    .310250
( 1.27136     )                ( 4.58862     ) ( 341.759     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 89770.1        .628031        1.5            4.20584
                               ( .4572       ) ( 1.28013     )

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                    RUN        7

     G2= 44ØØØ.
        ( 2Ø.7657      )
     Y1= .ØØ1                           Y2= 1.67944E-Ø2

     X1= .5624                          X2= .Ø446

     T3= 22Ø                            T2= 89
        ( 377.444      )                   ( 3Ø4.667      )


T4              Q IN          Q REQ          Q LOSS          % LOSS
 149.7           3.576Ø2E+Ø6   3.5Ø457E+Ø6    71455.5         1.99812
( 338.389     ) ( 1Ø47.79    ) ( 1Ø27.Ø5    ) ( 2Ø.94Ø7     )

FLUID VEL       REYNOLDS NO   H T COEFF      HEAT TRANS      % TRAN
 242.757         155.894       9.25832        759858.         .26841Ø
( 1.23321     )               ( 4.Ø8376    ) ( 281.294     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 10[illegible]01.   .627395        1.5             4.Ø2571
                              ( .4572      ) ( 1.227Ø4     )

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                    RUN        8

     G2= 44ØØØ.
        ( 2Ø.7657      )
     Y1= .ØØ1                           Y2= 1.67944E-Ø2

     X1= .5624                          X2= .Ø446

     T3= 24Ø                            T2= 93
        ( 388.556      )                   ( 3Ø6.889      )


T4              Q IN          Q REQ          Q LOSS          % LOSS
 168.6           3.63178E+Ø6   3.54589E+Ø6    86Ø86.          2.37Ø22
( 348.887     ) ( 1Ø64.39    ) ( 1Ø39.16    ) ( 25.2284     )

FLUID VEL       REYNOLDS NO   H T COEFF      HEAT TRANS      % TRAN
 258.279         183.173       7.19766        1.14567E+Ø6     .315427
( 1.27142     )               ( 4.8[illegible]  ) ( 335.75      )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 95757.5         .632637       1.5             4.Ø8315
                              ( .4572      ) ( 1.24434     )

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                    RUN        9

     G2= 44ØØØ.
        ( 2Ø.7657      )
     Y1= .ØØ1                           Y2= 1.67944E-Ø2

     X1= .5624                          X2= .Ø446

     T3= 26Ø                            T2= 96.5
        ( 399.667      )                   ( 3Ø8.833      )


T4              Q IN          Q REQ          Q LOSS          % LOSS
 157.5           3.6Ø798E+Ø6   3.5856ØE+Ø6    1Ø2332.         2.77472
( 357.[illegible]   ) ( 1Ø8Ø.79    ) ( 1Ø5Ø.8     ) ( 29.9894     )

FLUID VEL       REYNOLDS NO   H T COEFF      HEAT TRANS      % TRAN
 257.[illegible]     149.ØØ7       7.1Ø5Ø8        1.Ø82[illegible]E+Ø6    .362874
( 1.31[illegible]   )               ( 4.94529    ) ( 3[illegible]2.[illegible]     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 [illegible]         [illegible]        1.5             [illegible].1Ø146
                              ( .4572      ) ( 1.25[illegible]27     )

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                    RUN         10

     G2= 44000.
        ( 20.7657      )
     Y1= .0214                        Y2= 3.75163E-02

     X1= .5624                        X2= .0446

     T3= 220                          T2= 104
        ( 377.444      )                 ( 313  )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 149.9           3.62805E+06    3.55326E+06    74785.5        2.06131
( 338.5       ) ( 1063.24     ) ( 1041.32     ) ( 21.9166     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 246.291         155.894        9.25832        850605.        .234453
( 1.25116     )                ( 4.88376     ) ( 249.278     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 104860.         .629295        1.5            4.04635
                               ( .4572       ) ( 1.23333     )

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                    RUN         11

     G2= 44000.
        ( 20.7657      )
     Y1= .0214                        Y2= 3.75163E-02

     X1= .5624                        X2= .0446

     T3= 240                          T2= 107
        ( 388.556      )                 ( 314.667     )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 169.1           3.66945E+06    3.59181E+06    77641.5        2.11587
( 349.167     ) ( 1075.37     ) ( 1052.62     ) ( 22.7536     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 254.6           150.170        9.19766        1.05040E+06    .286277
( 1.29337     )                ( 4.85282     ) ( 307.853     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 94137.7         .634907        1.5            4.10854
                               ( .4572       ) ( 1.25228     )

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                    RUN         12

     G2= 44000.
        ( 20.7657      )
     Y1= .0214                        Y2= 3.75163E-02

     X1= .5624                        X2= .0446

     T3= 260                          T2= 109
        ( 399.667      )                 ( 315.778     )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 188             3.72628E+06    3.62660E+06    99700.5        2.67558
( 359.667     ) ( 1092.05     ) ( 1062.84     ) ( 29.2182     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 261.886         148.080        9.18330        1.25622E+06    .33711
( 1.33037     )                ( 4.84529     ) ( 368.140     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 85470.6         .639547        1.5            4.15142
                               ( .4572       ) ( 1.2654      )

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                  RUN        13

     G2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .ØØ1                         Y2= 1.61Ø77E-Ø2

     X1= .5624                        X2= .Ø446

     T3= 22Ø                          T2= 89
        ( 377.444     )                  ( 3Ø4.667     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 152.6          3.58435E+Ø6    3.5Ø893E+Ø6    75419.          2.1Ø412
( 34Ø  )       ( 1Ø5Ø.43     ) ( 1Ø28.33     ) ( 22.1Ø23     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 254.474        162.98         9.75256        1.Ø3234E+Ø6    .288Ø12
( 1.29273     )               ( 5.14448     ) ( 3Ø2.536     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 1Ø6Ø97.        .638153        1.5            4.1454
                              ( .4572       ) ( 1.26352     )

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                  RUN        14

     G2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .ØØ1                         Y2= 1.61Ø77E-Ø2

     X1= .5624                        X2= .Ø446

     T3= 24Ø                          T2= 93
        ( 388.556     )                  ( 3Ø6.889     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 171.5          3.64234E+Ø6    3.55Ø25E+Ø6    92593.          2.54178
( 35Ø.5       ) ( 1Ø67.57     ) ( 1Ø4Ø.44     ) ( 27.1339     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 262.315        156.779        9.69Ø78        1.22747E+Ø6    .336954
( 1.33256     )               ( 5.11189     ) ( 359.722     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 95519.4        .643422        1.5            4.2Ø665
                              ( .4572       ) ( 1.28219     )

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                  RUN        15

     G2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .ØØ1                         Y2= 1.61Ø77E-Ø2

     X1= .5624                        X2= .Ø446

     T3= 26Ø                          T2= 96.5
        ( 399.667     )                  ( 3Ø8.833     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 19Ø.6          3.69Ø71E+Ø6    3.59Ø26E+Ø6    1Ø8445.         2.7215Ø
( 361.111     ) ( 1Ø81.6      ) ( 1Ø52.16     ) ( 29.4366     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 27Ø.32Ø        135.371        9.67573        1.4Ø13ØE+Ø6    .387819
( 1.37327     )               ( 5.1Ø375     ) ( 41Ø.464     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 91817.3        .64773Ø        1.5            4.25879
                              ( .4572       ) ( 1.298Ø8     )

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                    RUN         16

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.68156E-02

     X1= .5624                        X2= .0446

     T3= 220                          T2= 104
        ( 377.444     )                  ( 313  )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 152.9           3.63064E+06     3.55777E+06     72863.          2.00687
( 340.167     ) ( 1063.99     ) ( 1042.64     ) ( 21.3532     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 258.319         162.98          9.75256         928372.         .255501
( 1.31226     )                 ( 5.14448     ) ( 269.724     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 104523.         .640159         1.5             4.16851
                                ( .4572       ) ( 1.27056     )

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                    RUN         17

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.68156E-02

     X1= .5624                        X2= .0446

     T3= 240                          T2= 107
        ( 388.556     )                  ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 172.1           3.67392E+06     3.59632E+06     77599.5         2.11217
( 350.833     ) ( 1076.68     ) ( 1053.94     ) ( 22.7413     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 266.95          156.999         9.69079         1.12950E+06     .307406
( 1.35611     )                 ( 5.11189     ) ( 331.01      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 93866.4         .645785         1.5             4.23471
                                ( .4572       ) ( 1.29074     )

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                    RUN         18

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.68156E-02

     X1= .5624                        X2= .0446

     T3= 260                          T2= 109
        ( 399.667     )                  ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 191             3.73344E+06     3.63120E+06     102247.         2.73869
( 361.333     ) ( 1094.12     ) ( 1064.16     ) ( 29.9646     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 275.699         155.371         9.67374         1.0[illegible]E+06     .360339
( 1.40055     )                 ( 5.10396     ) ( 294.255     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 87251.8         .650461         1.5             4.29126
                                ( .4572       ) ( 1.30[illegible]     )

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RUN
FLUID2

                   RUN        1

    G2= 42000.
       ( 19.8218     )
    Y1= .001                        Y2= 1.83195E-02

    X1= .5624                       X2= .02041

    T3= 220                         T2= 89
       ( 377.444     )                 ( 304.667     )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 143.1         3.73394E+06    3.65956E+06    74383.5        1.99209
( 334.722    ) ( 1094.27    ) ( 1072.47    ) ( 21.7988    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 230.243       148.807        8.76787        864213.        .231446
( 1.16963    )               ( 4.62505    ) ( 253.266    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 107063.       .615916        1.5            3.9054
                             ( .4572      ) ( 1.19037    )

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                   RUN        2

    G2= 42000.
       ( 19.8218     )
    Y1= .001                        Y2= 1.83195E-02

    X1= .5624                       X2= .02041

    T3= 240                         T2= 93
       ( 388.556     )                 ( 306.889     )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 161.7         3.79221E+06    3.70205E+06    90158.         2.37745
( 345.167    ) ( 1111.05    ) ( 1084.92    ) ( 26.4217    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 237.455       140.347        8.71201        1.04107E+06    .274528
( 1.20627    )               ( 4.59575    ) ( 305.075    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 96341.4       .621143        1.5            3.95903
                             ( .4572      ) ( 1.2069     )

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                   RUN        3

    G2= 42000.
       ( 19.8218     )
    Y1= .001                        Y2= 1.83195E-02

    X1= .5624                       X2= .02041

    T3= 260                         T2= 96.5
       ( 399.667     )                 ( [illegible]  )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 180.6         3.85538E+06    3.74270E+06    112556.        2.91747
( 355.556    ) ( 1129.04    ) ( 1096.86    ) ( 32.9857    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 244.734       142.044        8.69001        1.22310E+06    .31727
( 1.24325    )               ( 4.56662    ) ( 358.462    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 91793.1       .625377        1.5            4.00424
                             ( .4572      ) ( 1.22049    )

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                    RUN          4

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                      Y2= 3.90725E-02

     X1= .5624                      X2= .02041

     T3= 220                        T2= 104
        ( 377.444      )               ( 313   )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 143.4           3.79426E+06     3.70543E+06     75827.5         2.00376
( 334.869      ) ( 1109.01     ) ( 1086.79     ) ( 22.222      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 233.369         148.807         8.76737         756073.         .199774
( 1.18552      )                ( 4.62505     ) ( 221.575     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 105633.         .617657         1.5             3.92318
                                ( .4572       ) ( 1.19577     )

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                    RUN          5

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                      Y2= 3.90725E-02

     X1= .5624                      X2= .02041

     T3= 240                        T2= 107
        ( 388.556      )               ( 314.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 162.8           3.81390E+06     3.74864E+06     65257.          1.71103
( 345.667      ) ( 1117.7      ) ( 1098.58     ) ( 19.1242     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 241.476         143.347         8.71231         950243.         .249152
( 1.2268       )                ( 4.59575     ) ( 278.477     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94734.5         .620346         1.5             3.98243
                                ( .4572       ) ( 1.21384     )

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                    RUN          6

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                      Y2= 3.90725E-02

     X1= .5624                      X2= .02041

     T3= 260                        T2= 109
        ( 399.667      )               ( 315.778      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 181.5           3.87012E+06     3.78453E+06     93596.          2.41344
( 356.056      ) ( 1136.52     ) ( 1109.09     ) ( 27.4292     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 249.355         142.344         8.67001         1.14570E+06     .295414
( 1.26774      )                ( 4.58062     ) ( 335.768     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 86225.7         .627756         1.5             4.02178
                                ( .4572       ) ( 1.22589     )

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                   RUN         7

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 1.75323E-Ø2

     X1= .5624                         X2= .Ø2Ø41

     T3= 22Ø                           T2= 89
        ( 377.444     )                   ( 3Ø4.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 146.4          3.74307E+Ø6    3.66475E+Ø6    79134.         2.11369
( 336.556    ) ( 1Ø97.18    ) ( 1Ø73.99    ) ( 23.191     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 241.900        155.894        9.25832        936459.        .25Ø13
( 1.2293     )                ( 4.88376    ) ( 274.409    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 1Ø6718.        .626978        1.5            4.Ø2121
                              ( .4572      ) ( 1.22566    )

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                   RUN         8

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 1.75323E-Ø2

     X1= .5624                         X2= .Ø2Ø41

     T3= 24Ø                           T2= 93
        ( 388.556     )                   ( 3Ø6.889     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 165.3          3.79984E+Ø6    3.7Ø741E+Ø6    92409.         2.43268
( 347.Ø56    ) ( 1113.58    ) ( 1Ø86.49    ) ( 27.Ø899    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 249.580        15Ø.173        9.17966        1.12303E+Ø6    .295547
( 1.26765    )                ( 4.85282    ) ( 329.115    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 76Ø43.         .632244        1.5            4.Ø7879
                              ( .4572      ) ( 1.24322    )

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                   RUN         9

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 1.75323E-Ø2

     X1= .5624                         X2= .Ø2Ø41

     T3= 26Ø                           T2= 96.5
        ( 399.667     )                   ( 3Ø8.833     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 184.2          3.[illegible]E+Ø6    3.74944E+Ø6    1Ø7354.        2.78422
( 357.556    ) ( 1127.98    ) ( 1Ø98.52    ) ( 31.4612    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 257.[illegible]       148.[illegible]       9.1[illegible]       1.31611E+Ø6    .341333
( 1.3Ø653    )                ( 4.84529    ) ( 385.699    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 91537.5        .[illegible]3656       1.5            4.12[illegible]
                              ( .4572      ) ( 1.25798    )

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                    RUN        10

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                      Y2= 3.82692E-02

     X1= .5624                      X2= .02041

     T3= 220                        T2= 104
        ( 377.444     )                ( 313   )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 146.8          3.78849E+06    3.71078E+06    74712.         1.97200
( 336.778     ) ( 1110.26     ) ( 1088.36     ) ( 21.8951     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 245.447        155.894        9.25832        826083.        .218051
( 1.24687     )               ( 4.88376     ) ( 242.092     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 105219.        .628843        1.5            4.04142
                              ( .4572       ) ( 1.23182     )

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                    RUN        11

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                      Y2= 3.82692E-02

     X1= .5624                      X2= .02041

     T3= 240                        T2= 107
        ( 388.556     )                ( 314.667     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 165.9          3.83507E+06    3.75352E+06    81552.5        2.12649
( 347.389     ) ( 1123.91     ) ( 1100.01     ) ( 23.8998     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 253.788        150.173        9.19966        1.02[illegible]E+06    .26774
( 1.28924     )               ( 4.85282     ) ( 300.915     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 74439.8        .634483        1.5            4.10378
                              ( .4572       ) ( 1.25083     )

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                    RUN        12

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                      Y2= 3.82692E-02

     X1= .5624                      X2= .02041

     T3= 260                        T2= 109
        ( 399.667     )                ( 315.778     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 184.7          3.89710E+06    3.78956E+06    107614.        2.761[illegible]4
( 357.000     ) ( 1142.11     ) ( 1110.57     ) ( 31.5375     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 262.211        148.880        9.10508        1.23234E+06    .316342
( 1.33283     )               ( 4.84529     ) ( 361.295     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 87761.2        .639142        1.5            4.15676
                              ( .4572       ) ( 1.26698     )

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                    RUN         13

    G2= 46000.
       ( 21.7096     )
    Y1= .001                          Y2= 1.68135E-02

    X1= .5624                         X2= .02041

    T3= 220                           T2= 89
       ( 377.444     )                   ( 304.667     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 149.6          3.74089E+06    3.66979E+06    74096.5        1.97910
( 338.333     ) ( 1097.18     ) ( 1075.47     ) ( 21.7147     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 250.767        162.98         9.75256        1.01035E+06    .269867
( 1.20914     )               ( 5.14448     ) ( 296.094     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 106372.        .637792        1.5            4.14115
                              ( .4572       ) ( 1.26222     )

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                    RUN         14

    G2= 46000.
       ( 21.7096     )
    Y1= .001                          Y2= 1.68135E-02

    X1= .5624                         X2= .02041

    T3= 240                           T2= 93
       ( 388.556     )                   ( 306.889     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 168.5          3.80230E+06    3.71244E+06    89740.         2.36544
( 348.833     ) ( 1114.38     ) ( 1087.97     ) ( 26.3507     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 261.632        158.997        9.69079        1.20611E+06    .317197
( 1.32707     )               ( 5.11189     ) ( 353.463     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 95760.2        .64507         1.5            4.2225
                              ( .4572       ) ( 1.28092     )

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                    RUN         15

    G2= 46000.
       ( 21.7096     )
    Y1= .001                          Y2= 1.68135E-02

    X1= .5624                         X2= .02041

    T3= 260                           T2= 96.5
       ( 399.667     )                   ( 308.833     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 187.4          3.86088E+06    3.75348E+06    107404.        2.78186
( 359.333     ) ( 1131.47     ) ( 1099.99     ) ( 31.475      )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 269.[illegible]    155.371        9.67574        1.42[illegible]E+06   .364941
( 1.36962     )               ( 5.10396     ) ( 412.92      )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 91261.2        .[illegible]    1.5            4.25443
                              ( .4572       ) ( 1.29675     )

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                    RUN          16

     G2= 46ØØØ.
        ( 21.7Ø96      )
     Y1= .Ø214                        Y2= 3.75358E-Ø2

     X1= .5624                        X2= .Ø2Ø41

     T3= 22Ø                          T2= 1Ø4
        ( 377.444      )                 ( 313   )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 149.9           3.79296E+Ø6     3.71866E+Ø6     743Ø1.5         1.95893
( 338.5       ) ( 1111.56      ) ( 1Ø89.79      ) ( 21.7748      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 257.49          162.98          9.75256         896Ø14.         .236231
( 1.3Ø8Ø5      )                ( 5.14448      ) ( 262.586      )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 1Ø4Ø58.         .639729        1.5             4.16353
                                ( .4572        ) ( 1.269Ø4      )

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                    RUN          17

     G2= 46ØØØ.
        ( 21.7Ø96      )
     Y1= .Ø214                        Y2= 3.75358E-Ø2

     X1= .5624                        X2= .Ø2Ø41

     T3= 24Ø                          T2= 1Ø7
        ( 388.556      )                 ( 314.667      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 167.3           3.82543E+Ø6     3.75887E+Ø6     66556.          1.73981
( 347.278      ) ( 1121.Ø8      ) ( 11Ø1.57      ) ( 19.5Ø49      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 266.238         156.999         9.69Ø78         1.1Ø818E+Ø6     .289667
( 1.35249      )                ( 5.11189      ) ( 324.74       )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 94116.5         .645424        1.5             4.2Ø34
                                ( .4572        ) ( 1.28943      )

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                    RUN          18

     G2= 46ØØØ.
        ( 21.7Ø96      )
     Y1= .Ø214                        Y2= 3.75358E-Ø2

     X1= .5624                        X2= .Ø2Ø41

     T3= 26Ø                          T2= 1Ø9
        ( 399.667      )                 ( 315.778      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 187.9           3.9Ø11ØE+Ø6     3.7946ØE+Ø6     1Ø6538.         2.732
( 359.611      ) ( 1143.28      ) ( 1112.Ø4      ) ( 31.2Ø48      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 274.935         155.571         9.67573         1.32252E+Ø6     .3Ø98Ø6
( 1.39667      )                ( 5.1Ø395      ) ( 387.573      )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 89479.          .65Ø2Ø3        1.5             4.2Ø173
                                ( .4572        ) ( 1.2866       )

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RUB+N
FLUID2

                    RUN         1

     G2= 42000.
        ( 19.8218     )
     Y1= .001                          Y2= 1.54598E-02

     X1= .4705                         X2= .0446

     T3= 220                           T2= 89
        ( 377.444     )                   ( 304.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 155.7            3.12214E+06    3.06378E+06     58357.5         1.86915
( 341.722     ) ( 914.974     ) ( 897.872     ) ( 17.1022     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 233.013         148.807         8.76787         948166.         .303691
( 1.18371     )                 ( 4.62505     ) ( 277.87      )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 105794.         .61746          1.594           4.16689
                                ( .485851     ) ( 1.27007     )

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                    RUN         2

     G2= 42000.
        ( 19.8218     )
     Y1= .001                          Y2= 1.54598E-02

     X1= .4705                         X2= .0446

     T3= 240                           T2= 93
        ( 388.556     )                   ( 306.869     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 174.5            3.18041E+06    3.10220E+06     78211.          2.45915
( 352.167     ) ( 932.05      ) ( 909.13      ) ( 22.7205     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 240.129         143.347         8.71231         1.12247E+06     .352932
( 1.21986     )                 ( 4.59575     ) ( 328.75      )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 95272.          .622606         1.594           4.2237
                                ( .485851     ) ( 1.28738     )

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                    RUN         3

     G2= 42000.
        ( 19.8218     )
     Y1= .001                          Y2= 1.54598E-02

     X1= .4705                         X2= .0446

     T3= 260                           T2= 96.5
        ( 399.667     )                   ( 308.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 193.5            3.22897E+06    3.13916E+06     89804.          2.7812
( 362.722     ) ( 946.201     ) ( 919.960     ) ( 26.318      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 247.403         142.044         8.69831         1.30479E+06     .40409
( 1.25602     )                 ( 4.58862     ) ( 382.083     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 98805.2         .62662          1.594           4.27139
                                ( .485851     ) ( 1.30192     )

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                    RUN         4

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                        Y2= 3.61545E-02

     X1= .4705                        X2= .0446

     T3= 220                          T2= 104
        ( 377.444      )                 ( 313  )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 155.8           3.17166E+06     3.11533E+06     56329.          1.77601
( 341.778     ) ( 929.487     ) ( 912.98      ) ( 16.5078     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 236.574         148.807         8.76787         848125.         .267407
( 1.2018      )                 ( 4.62505     ) ( 248.551     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 104207.         .619423         1.594           4.16838
                                ( .485851     ) ( 1.27662     )

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                    RUN         5

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                        Y2= 3.61545E-02

     X1= .4705                        X2= .0446

     T3= 240                          T2= 107
        ( 388.556      )                 ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 175.2           3.20130E+06     3.15111E+06     50194.          1.56792
( 352.556     ) ( 938.174     ) ( 923.464     ) ( 14.7099     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 244.466         143.347         8.71231         1.03639E+06     .32374
( 1.24189     )                 ( 4.59575     ) ( 303.724     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 93587.3         .624942         1.594           4.25001
                                ( .485851     ) ( 1.2954      )

******************************************************************

                    RUN         6

     G2= 42000.
        ( 19.8218      )
     Y1= .0214                        Y2= 3.61545E-02

     X1= .4705                        X2= .0446

     T3= 260                          T2= 109
        ( 399.667      )                 ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 194             3.26059E+06     3.18267E+06     77918.5         2.38971
( 363  )        ( 955.547     ) ( 932.710     ) ( 22.8348     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 252.395         142.044         8.69[illegible]1       1.22902E+06     .376932
( 1.28217     )                 ( 4.58362     ) ( 360.176     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 [illegible]15.6         .627445         1.594           4.30166
                                ( .485851     ) ( 1.31115     )
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                    RUN        7

     G2= 44000.
        ( 20.7657    )
     Y1= .001                       Y2= 1.48025E-02

     X1= .4705                      X2= .0446

     T3= 220                        T2= 89
        ( 377.444    )                 ( 304.667    )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 158.5           3.12838E+06    3.06746E+06    60922.5        1.94741
( 343.278    ) ( 916.804    ) ( 898.95     ) ( 17.8539    )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 244.713         155.994        9.25832        1.02003E+06    .326056
( 1.24314    )                ( 4.88376    ) ( 298.93     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 105534.         .628449        1.594          4.29813
                              ( .485851    ) ( 1.30763    )

*****************************************************************

                    RUN        8

     G2= 44000.
        ( 20.7657    )
     Y1= .001                       Y2= 1.48025E-02

     X1= .4705                      X2= .0446

     T3= 240                        T2= 93
        ( 388.556    )                 ( 306.889    )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 177.4           3.18434E+06    3.10601E+06    78331.5        2.4599
( 353.778    ) ( 933.202    ) ( 910.247    ) ( 22.9558    )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 252.179         150.173        9.19966        1.20433E+06    .378203
( 1.28107    )                ( 4.85282    ) ( 352.94     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 95040.4         .633639        1.594          4.3509
                              ( .485851    ) ( 1.32615    )

*****************************************************************

                    RUN        9

     G2= 44000.
        ( 20.7657    )
     Y1= .001                       Y2= 1.48025E-02

     X1= .4705                      X2= .0446

     T3= 260                        T2= 96.5
        ( 399.667    )                 ( 308.833    )


T4              Q IN           Q REQ          Q LOSS         % LOSS
 196.6           3.22503E+06    3.14323E+06    81799.5        2.53639
( 364.444    ) ( 945.120    ) ( 921.156    ) ( 23.9722    )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 259.838         148.607        9.18538        1.39785E+06    .433437
( 1.31978    )                ( 4.84529    ) ( 409.654    )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 90578.3         .637926        1.594          4.40242
                              ( .485851    ) ( 1.34186    )

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                       RUN          10

     G2= 44000.
         ( 20.7657    )
     Y1= .0214                       Y2= 3.54839E-02

     X1= .4705                       X2= .0446

     T3= 220                         T2= 104
        ( 377.444     )                 ( 313   )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 158.6            3.17778E+06    3.11901E+06     58765.          1.94925
( 343.333     ) ( 931.28      ) ( 914.058     ) ( 17.2217     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 248.541          155.894        9.25832         916212.         .288318
( 1.26259     )                 ( 4.88076     ) ( 268.505     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 103914.          .630494        1.594           4.31387
                                ( .485851     ) ( 1.31487     )

*****************************************************************

                       RUN          11

     G2= 44000.
         ( 20.7657    )
     Y1= .0214                       Y2= 3.54839E-02

     X1= .4705                       X2= .0446

     T3= 240                         T2= 107
         ( 388.556    )                 ( 314.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 178.1            3.20366E+06    3.15492E+06     48738.          1.52126
( 354.167     ) ( 938.898     ) ( 924.581     ) ( 14.2829     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 256.797          150.17[illegible]  9.19966      1.11470E+06     .347947
( 1.30453     )                 ( 4.85282     ) ( 326.675     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 93336.7          .63605         1.594           4.37973
                                ( .485851     ) ( 1.33494     )

*****************************************************************

                       RUN          12

     G2= 44000.
         ( 20.7657    )
     Y1= .0214                       Y2= 3.54839E-02

     X1= .4705                       X2= .0446

     T3= 260                         T2= 109
         ( 399.667    )                 ( 315.778     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 196.8            3.27094E+06    3.18635E+06     84589.5         2.58609
( 364.556     ) ( 958.581     ) ( 933.791     ) ( 24.7898     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 265.047          148.807        9.18538         1.31679E+06     .402571
( 1.34644     )                 ( 4.84529     ) ( 385.897     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 88803.6          .640582        1.594           4.43495
                                ( .485851     ) ( 1.35177     )

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                    RUN        13

     G2= 46000.
         ( 21.7096     )
     Y1= .001                          Y2= 1.42024E-02

     X1= .4705                         X2= .0446

     T3= 220                           T2= 89
         ( 377.444     )                   ( 304.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 161.1           3.13231E+06     3.07088E+06     61436.          1.96136
( 344.722     ) ( 917.956     ) ( 899.951     ) ( 18.0044     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 256.415         162.98          9.75256         1.09264E+06     .348620
( 1.30259     )                 ( 5.14448     ) ( 320.209     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 105276.         .639169         1.594           4.41758
                                ( .485851     ) ( 1.34648     )

*************************************************************************

                    RUN        14

     G2= 46000.
         ( 21.7096     )
     Y1= .001                          Y2= 1.42024E-02

     X1= .4705                         X2= .0446

     T3= 240                           T2= 93
         ( 388.556     )                   ( 306.889     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 180.1           3.18549E+06     3.10956E+06     75938.          2.38397
( 355.278     ) ( 933.541     ) ( 911.236     ) ( 22.2544     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 264.233         156.779         9.69078         1.28710E+06     .404051
( 1.34231     )                 ( 5.11189     ) ( 377.190     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94828.3         .644408         1.594           4.48261
                                ( .485851     ) ( 1.36630     )

*************************************************************************

                    RUN        15

     G2= 46000.
         ( 21.7096     )
     Y1= .001                          Y2= 1.42024E-02

     X1= .4705                         X2= .0446

     T3= 260                           T2= 96.5
         ( 399.667     )                   ( 308.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 199.2           3.23306E+06     3.14665E+06     86707.5         2.68165
( 365.889     ) ( 947.568     ) ( 922.157     ) ( 25.4105     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 272.202         155.571         9.67573         1.49002E+06     .460529
( 1.38278     )                 ( 5.10395     ) ( 436.667     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 90395.          .643725         1.594           4.50775
                                ( .485851     ) ( [illegible] )

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                    RUN          16

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.48715E-02

     X1= .4705                        X2= .0446

     T3= 220                          T2= 104
        ( 377.444     )                  ( 313  )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 161.3            3.17613E+06     3.12256E+06     53572.5         1.68672
( 344.833     ) ( 930.798     ) ( 715.098     ) ( 15.7        )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 260.505          162.98          9.73256         985695.         .310344
( 1.02052     )                 ( 5.14448     ) ( 288.368     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 103637.          .641305         1.594           4.44357
                                ( .485851     ) ( 1.3545      )

*****************************************************************

                    RUN          17

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.48715E-02

     X1= .4705                        X2= .0446

     T3= 240                          T2= 107
        ( 388.556     )                  ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 180.2            3.23565E+06     3.15768E+06     77971.          2.40975
( 355.333     ) ( 948.239     ) ( 925.389     ) ( 22.8502     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 268.957          156.999         9.69078         1.18953E+06     .367621
( 1.0660      )                 ( 5.11189     ) ( 348.633     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 73168.1          .646798         1.594           4.513
                                ( .485851     ) ( 1.37556     )

*****************************************************************

                    RUN          18

     G2= 46000.
        ( 21.7096     )
     Y1= .0214                        Y2= 3.48715E-02

     X1= .4705                        X2= .0446

     T3= 260                          T2= 109
        ( 399.667     )                  ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 199.6            3.26811E+06     3.19033E+06     78028.5         2.3894
( 366.111     ) ( 957.754     ) ( 934.889     ) ( 22.8646     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 277.76           155.572         9.67574         1.40699E+06     .430489
( 1.41102     )                 ( 5.10396     ) ( 412.332     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 68591.8          .651476         1.594           4.57357
                                ( .485851     ) ( 1.39402     )

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RUN
FLUID2

                    RUN          1

     G2= 42000.
        ( 19.8218     )
     Y1= .001                        Y2= 1.96349E-02

     X1= .6667                       X2= .0446

     T3= 220                         T2= 89
        ( 377.444     )                 ( 304.667     )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 137.3           4.01557E+06    3.93259E+06    82980.5        2.06647
( 331.5       ) ( 1176.8     ) ( 1152.48    ) ( 24.3183    )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 228.066         148.807        8.76787        823107.        .204979
( 1.16264     )                ( 4.62505    ) ( 241.22     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 107705.         .615143        1.406          3.65331
                               ( .428549    ) ( 1.11353    )

*****************************************************************

                    RUN          2

     G2= 42000.
        ( 19.8218     )
     Y1= .001                        Y2= 1.96349E-02

     X1= .6667                       X2= .0446

     T3= 240                         T2= 93
        ( 388.556     )                 ( 306.889     )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 156.1           4.07383E+06    3.97652E+06    97312.5        2.38872
( 341.944     ) ( 1193.68    ) ( 1165.36    ) ( 28.5184    )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 236.146         143.347        8.71231        1.00175E+06    .245898
( 1.19962     )                ( 4.59575    ) ( 293.572    )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 96073.8         .62043         1.406          3.70[illegible]
                               ( .428549    ) ( 1.12904    )

*****************************************************************

                    RUN          3

     G2= 42000.
        ( 19.8218     )
     Y1= .001                        Y2= 1.96349E-02

     X1= .6667                       X2= .0446

     T3= 260                         T2= 96.5
        ( 399.667     )                 ( 308.833     )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 175             4.12725E+06    [illegible]    [illegible]    2.62[illegible]
( 352.444     ) ( 1207.50    ) ( 1177.04    ) ( 31.[illegible] )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 243.[illegible] 142.044        8.[illegible]  1.18[illegible]E+06 .[illegible]
( 1.23712     )                ( 4.58862    ) ( 347.666    )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 722[illegible]  .624791        1.4[illegible] 3.74[illegible]
                               ( .428549    ) ( 1.14204    )

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                    RUN        4

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                        Y2= 4.04147E-02

     X1= .6667                        X2= .0446

     T3= 220                          T2= 104
        ( 377.444     )                  ( 313   )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 138             4.05103E+06     3.97914E+06     71891.          1.77463
( 331.889     ) ( 1187.2      ) ( 1166.13     ) ( 21.0684     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 231.837         143.807         8.76787         712435.         .175865
( 1.17773     )                 ( 4.62585     ) ( 208.786     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106327.         .616036         1.406           3.66716
                                ( .428549     ) ( 1.11836     )

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                    RUN        5

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                        Y2= 4.04147E-02

     X1= .6667                        X2= .0446

     T3= 240                          T2= 107
        ( 388.556     )                  ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 157.4           4.08867E+06     4.02107E+06     59608.          1.46074
( 342.667     ) ( 1195.88     ) ( 1178.41     ) ( 17.4687     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 240.118         143.347         8.71231         910442.         .223111
( 1.2198      )                 ( 4.59575     ) ( 266.814     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 95276.5         .622599         1.406           3.72548
                                ( .428549     ) ( 1.13553     )

*****************************************************************

                    RUN        6

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                        Y2= 4.04147E-02

     X1= .6667                        X2= .0446

     T3= 260                          T2= 109
        ( 399.667     )                  ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 175.7           4.16466E+06     4.05010E+06     106554.         2.53054
( 352.833     ) ( 1220.49     ) ( 1189.27     ) ( 31.2269     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 248.154         142.044         8.69001         1.17529E+06     .293387
( 1.26062     )                 ( 4.58852     ) ( 323.906     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 90502.1         .627216         1.406           3.77102
                                ( .428549     ) ( 1.14959     )

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                    RUN         7

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                         Y2= 1.87878E-Ø2

     X1= .6667                        X2= .Ø446

     T3= 22Ø                          T2= 89
        ( 377.444     )                  ( 3Ø4.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 141            4.Ø1857E+Ø6    3.93885E+Ø6    79721.         1.98381
( 333.556    ) ( 1177.68    ) ( 1154.32    ) ( 23.363     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 24Ø.692        155.894        9.25832        897Ø55.        .22322
( 1.22271    )                ( 4.88376    ) ( 262.891    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 1Ø7291.        .626274        1.4Ø6          3.76211
                              ( .428549    ) ( 1.14669    )

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                    RUN         8

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                         Y2= 1.87878E-Ø2

     X1= .6667                        X2= .Ø446

     T3= 24Ø                          T2= 93
        ( 388.556     )                  ( 3Ø6.889     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 159.8          4.Ø7962E+Ø6    3.98279E+Ø6    96829.         2.37348
( 344  )       ( 1195.57    ) ( 1167.2     ) ( 28.3767    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 248.271        15Ø.173        9.19966        1.08443E+Ø6    .265816
( 1.26122    )                ( 4.85282    ) ( 317.882    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 96531.5        .631571        1.4Ø6          3.8162
                              ( .428549    ) ( 1.16318    )

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                    RUN         9

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                         Y2= 1.87878E-Ø2

     X1= .6667                        X2= .Ø446

     T3= 26Ø                          T2= 96.5
        ( 399.667     )                  ( 3Ø8.833     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 173.8          4.13Ø49E+Ø6    4.Ø2555E+Ø6    1Ø4933.        2.54Ø53
( 354.556    ) ( 121Ø.48    ) ( 1179.73    ) ( 3Ø.7533    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 255.996        148.3Ø7        9.18533        1.2792ØE+Ø6    .3Ø9693
( 1.3ØØ46    )                ( 4.84529    ) ( 374.883    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 917[illegible]     .6Ø594         1.4Ø6          3.862
                              ( .428549    ) ( 1.17714    )

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                RUN        10

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                    Y2= 3.95504E-02

    X1= .6667                    X2= .0446

    T3= 220                      T2= 104
       ( 377.444     )              ( 313   )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 141.7         4.05244E+06    3.98541E+06    67037.5         1.65425
( 333.944   ) ( 1187.61    ) ( 1167.96    ) ( 19.646     )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 243.999       155.894        9.25832        784151.        .193501
( 1.23952   )                ( 4.88376    ) ( 229.803    )

ARCHIMEDES NO BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 105842.       .628065        1.406          3.78023
                             ( .428549    ) ( 1.15221    )

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                RUN        11

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                    Y2= 3.95504E-02

    X1= .6667                    X2= .0446

    T3= 240                      T2= 107
       ( 388.556     )              ( 314.667     )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 161           4.08867E+06    4.02716E+06    61511.          1.50442
( 344.667   ) ( 1198.23    ) ( 1180.2     ) ( 18.0264    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 252.529       150.173        9.19966        989569.        .242027
( 1.28284   )                ( 4.85282    ) ( 290.003    )

ARCHIMEDES NO BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 94709.3       .633822        1.406          3.83967
                             ( .428549    ) ( 1.17033    )

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                RUN        12

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                    Y2= 3.95504E-02

    X1= .6667                    X2= .0446

    T3= 260                      T2= 109
       ( 399.667     )              ( 315.778     )


T4            Q IN           Q REQ          Q LOSS         % LOSS
 179.5         4.16631E+06    4.06454E+06    101756.         2.44261
( 354.944   ) ( 1220.98    ) ( 1191.15    ) ( 29.8237    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 260.742       148.807        9.10508        1.17520E+06    .209001
( 1.32556   )                ( 4.84529    ) ( 350.275    )

ARCHIMEDES NO BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 90196.4       .630493        1.406          3.80727
                             ( .428549    ) ( 1.18545    )

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                 RUN        13

     G2= 46000.
        ( 21.7096      )
     Y1= .001                            Y2= 1.80145E-02

     X1= .6667                           X2= .0446

     T3= 220                             T2= 89
        ( 377.444      )                    ( 304.667      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 144.3           4.02574E+06     3.94444E+06     81381.          2.01953
( 335.389     ) ( 1179.78     ) ( 1155.96     ) ( 23.8261     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 252.467         162.93          9.75256         970432.         .241072
( 1.28253     )                 ( 5.14448     ) ( 284.412     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 106938.         .637077         1.406           3.87431
                                ( .428549     ) ( 1.18089     )

*****************************************************************

                 RUN        14

     G2= 46000.
        ( 21.7096      )
     Y1= .001                            Y2= 1.80145E-02

     X1= .6667                           X2= .0446

     T3= 240                             T2= 93
        ( 388.556      )                    ( 306.889      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 163.2           4.08424E+06     3.98854E+06     95695.5         2.34304
( 345.889     ) ( 1196.93     ) ( 1168.88     ) ( 28.0445     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 260.381         156.799         9.69079         1.16760E+06     .285877
( 1.32274     )                 ( 5.11189     ) ( 342.176     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 76226.5         .642426         1.406           3.93205
                                ( .428549     ) ( 1.19849     )

*****************************************************************

                 RUN        15

     G2= 46000.
        ( 21.7096      )
     Y1= .001                            Y2= 1.80145E-02

     X1= .6667                           X2= .0446

     T3= 260                             T2= 96.5
        ( 399.667      )                    ( 309.833      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 182             4.14806E+06     4.03097E+06     117092.         2.82281
( 356.333     ) ( 1215.63     ) ( 1181.31     ) ( 34.315      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 260.371         155.571         9.67774         1.37014E+06     .33040
( 1.36033     )                 ( 5.10396     ) ( 401.68      )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 71601.          .641083         1.406           3.98273
                                ( .428549     ) ( 1.21394     )

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                    RUN          16

    G2= 46000.
       ( 21.7096      )
    Y1= .0214                         Y2= 3.87612E-02

    X1= .6667                         X2= .0446

    T3= 220                           T2= 104
       ( 377.444      )                  ( 313   )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 145             4.05809E+06     3.99099E+06     67095.5         1.653[illegible]
( 335.778     ) ( 1189.26     ) ( 1169.6      ) ( 19.663      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 256.088         162.98          9.75256         854045.         .210652
( 1.30092     )                 ( 5.14448     ) ( 250.521     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 105431.         .638978         1.406           3.89472
                                ( .428549     ) ( 1.18711     )

*****************************************************************

                    RUN          17

    G2= 46000.
       ( 21.7096      )
    Y1= .0214                         Y2= 3.87612E-02

    X1= .6667                         X2= .0446

    T3= 240                           T2= 107
       ( 388.556      )                  ( 314.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 164.5           4.08514E+06     4.03309E+06     52055.5         1.27426
( 346.611     ) ( 1197.19     ) ( 1181.94     ) ( 15.2554     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 264.977         156.777         9.69079         1.07[illegible]E+06     .262[illegible]
( 1.34609     )                 ( 5.11189     ) ( 313.734     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94562.3         .644794         1.406           3.95815
                                ( .428549     ) ( 1.20644     )

*****************************************************************

                    RUN          18

    G2= 46000.
       ( 21.7096      )
    Y1= .0214                         Y2= 3.87612E-02

    X1= .6667                         X2= .0446

    T3= 260                           T2= 109
       ( 399.667      )                  ( 315.778      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 183             4.16601E+06     4.07047E+06     95540.5         2.30[illegible]
( 356.889     ) ( 1220.98     ) ( 1192.8[illegible]     ) ( 28.007      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 273.716         155.571         9.67574         1.23[illegible]E+06     .30[illegible]
( 1.3984[illegible]     )                 ( 5.10396     ) ( 275.[illegible]     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 89[illegible].3         .649479         1.406           4.[illegible]
                                ( .428549     ) ( 1.2[illegible]     )

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```
RUN
FLUID2

                      RUN          1

   G2= 42ØØØ.
      ( 19.8218      )
   Y1= .ØØ1                             Y2= 2.15Ø42E-Ø2

   X1= .5625                            X2= .Ø4493

   T3= 22Ø                              T2= 89
      ( 377.444      )                     ( 3Ø4.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 129.5           4.3943ØE+Ø6     4.3Ø514E+Ø6     89162.          2.Ø29Ø4
( 327.167     ) ( 1287.79     ) ( 1261.66     ) ( 26.1298     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 226.9Ø1         148.8Ø7         8.76787         764661.         .174Ø12
( 1.15266     )                 ( 4.625Ø5     ) ( 224.Ø91     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 1Ø8634.         .614Ø35         1.86            4.819Ø9
                                ( .566928     ) ( 1.46886     )

*****************************************************************

                      RUN          2

   G2= 42ØØØ.
      ( 19.8218      )
   Y1= .ØØ1                             Y2= 2.15Ø42E-Ø2

   X1= .5625                            X2= .Ø4493

   T3= 24Ø                              T2= 93
      ( 388.556      )                     ( 3Ø6.889      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 148             4.46714E+Ø6     4.35561E+Ø6     111525.         2.49657
( 337.444     ) ( 1309.14     ) ( 1276.46     ) ( 32.6835     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 234.223         143.347         8.71201         944442.         .21142
( 1.18985     )                 ( 4.59575     ) ( 276.778     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 97666.3         .619069         1.86            4.88662
                                ( .566928     ) ( 1.48944     )

*****************************************************************

                      RUN          3

   G2= 42ØØØ.
      ( 19.8218      )
   Y1= .ØØ1                             Y2= 2.15Ø42E-Ø2

   X1= .5625                            X2= .Ø4493

   T3= 26Ø                              T2= 96.5
      ( 399.667      )                     ( 3Ø8.833      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 166.6           4.53512E+Ø6     4.4Ø427E+Ø6     130848.         2.88522
( 347.778     ) ( 1329.Ø6     ) ( 1290.71     ) ( 38.3463     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 241.617         142.Ø44         8.67001         1.12714E+Ø6     .248977
( 1.22742     )                 ( 4.58862     ) ( 33Ø.9Ø5     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 92973.4         .620721         1.86            4.94014
                                ( .566928     ) ( 1.5Ø667     )

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                    RUN         4

    G2= 42000.
       ( 19.8218      )
    Y1= .0214                        Y2= .042322

    X1= .5625                        X2= .04493

    T3= 220                          T2= 104
       ( 377.444      )                 ( 313   )

T4            Q IN           Q REQ          Q LOSS         % LOSS
 129.8          4.45614E+06    4.36570E+06    90435.          2.02945
( 327.333    ) ( 1305.92    ) ( 1279.41    ) ( 26.5029    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 229.239       148.807        8.76787        640252.        .143679
( 1.16453    )               ( 4.62505    ) ( 187.632    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 107530.        .615354       1.86           4.83561
                             ( .566928    ) ( 1.47389    )

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                    RUN         5

    G2= 42000.
       ( 19.8218      )
    Y1= .0214                        Y2= .042322

    X1= .5625                        X2= .04493

    T3= 240                          T2= 107
       ( 388.556      )                 ( 314.667     )

T4            Q IN           Q REQ          Q LOSS         % LOSS
 149            4.49566E+06    4.41347E+06    82190.          1.82825
( 338  )       ( 1317.5     ) ( 1293.41    ) ( 24.0845    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 237.709       143.347        8.71201        844999.        .187957
( 1.20797    )               ( 4.59575    ) ( 247.636    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 96206.4        .621331       1.86           4.91194
                             ( .566928    ) ( 1.49716    )

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                    RUN         6

    G2= 42000.
       ( 19.8218      )
    Y1= .0214                        Y2= .042322

    X1= .5625.                       X2= .04493

    T3= 260                          T2= 109
       ( 399.667      )                 ( 315.778     )

T4            Q IN           Q REQ          Q LOSS         % LOSS
 167.5          4.56976E+06    4.45595E+06    113816.         2.49063
( 348.278    ) ( 1339.21    ) ( 1305.86    ) ( 33.3549    )

FLUID VEL     REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 246.872       142.344        8.69581        1.04568E+06    .228815
( 1.25005    )               ( 4.58862    ) ( 306.432    )

ARCHIMEDES NO  BED VOIDAGE   PACKED HEIGHT  EXPANDED HEIGHT
 91295.7        .626111       1.86           4.97474
                             ( .566928    ) ( 1.5163     )

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                    RUN         7

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 2.Ø5722E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 22Ø                           T2= 89
        ( 377.444     )                   ( 3Ø4.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 133.5           4.4ØØØØE+Ø6     4.31259E+Ø6     87490.          1.98837
( 329.389     ) ( 1289.49     ) ( 1263.85     ) ( 25.6398     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 238.788         155.Ø94         9.25832         839614.         .1908[illegible]
( 1.213Ø4     )                 ( 4.88376     ) ( 246.Ø57     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 1Ø814[illegible].       .625234         1.86            4.9631
                                ( .566928     ) ( 1.51275     )

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                    RUN         8

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 2.Ø5722E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 24Ø                           T2= 93
        ( 388.556     )                   ( 3Ø6.889     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 152             4.47639E+Ø6     4.36306E+Ø6     113321.         2.53153
( 339.667     ) ( 1311.85     ) ( 1278.64     ) ( 33.2Ø98     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 246.386         150.173         9.19966         1.Ø2755E+Ø6     .229547
( 1.25164     )                 ( 4.85282     ) ( 3Ø1.134     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 97267.5         .63Ø565         1.86            5.Ø3471
                                ( .566928     ) ( 1.53458     )

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                    RUN         9

     G2= 44ØØØ.
        ( 2Ø.7657     )
     Y1= .ØØ1                          Y2= 2.Ø5722E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 26Ø                           T2= 96.5
        ( 399.667     )                   ( 3Ø8.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 17Ø.7           4.54252E+Ø6     4.41191E+Ø6     [illegible]     2.87524
( 35Ø.Ø56     ) ( 1331.23     ) ( 1292.95     ) ( 38.276      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 254.11          [illegible]     [illegible]     1.2221ØE+Ø6     .26[illegible]
( 1.29Ø63     )                 ( 4.84529     ) ( 358.147     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 [illegible]     [illegible]     1.86            5.[illegible]
                                ( .566928     ) ( 1.55304     )

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                   RUN         10

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                         Y2= .041371

     X1= .5625                         X2= .04493

     T3= 220                           T2= 104
        ( 377.444     )                   ( 313   )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 134.1           4.44578E+06     4.37371E+06     72071.           1.62111
( 329.722     ) ( 1302.88     ) ( 1281.76     ) ( 21.1211     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 241.636         155.894         9.25832         717123.         .161304
( 1.22751     )                 ( 4.88376     ) ( 210.16      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106873.         .626787         1.86            4.98575
                                ( .566928     ) ( 1.51905     )

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                   RUN         11

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                         Y2= .041371

     X1= .5625                         X2= .04493

     T3= 240                           T2= 107
        ( 388.556     )                   ( 314.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 152.9           4.50789E+06     4.42074E+06     87149.           1.93325
( 340.167     ) ( 1321.08     ) ( 1295.54     ) ( 25.5399     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 250.259         150.173         9.19966         924976.         .20519
( 1.27132     )                 ( 4.85282     ) ( 271.074     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 75767.1         .632626         1.86            5.06297
                                ( .566928     ) ( 1.54319     )

*****************************************************************

                   RUN         12

     G2= 44000.
        ( 20.7657     )
     Y1= .0214                         Y2= .041371

     X1= .5625                         X2= .04493

     T3= 260                           T2= 109
        ( 399.667     )                   ( 315.778     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 171.5           4.58035E+06     4.46340E+06     116949.          2.55328
( 350.5       ) ( 1342.32     ) ( 1308.04     ) ( 34.2731     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 258.867         148.007         9.18538         1.13520E+06     .247840
( 1.31504     )                 ( 4.84529     ) ( 332.691     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 90717.          .637426         1.86            5.12998
                                ( .566928     ) ( 1.56362     )

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                    RUN          13

    G2= 46000.
       ( 21.7096      )
    Y1= .001                          Y2= 1.97212E-02

    X1= .5625                         X2= .04493

    T3= 220                           T2= 89
       ( 377.444      )                  ( 304.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 137.1           4.40864E+06     4.31930E+06     89336.          2.02639
( 331.389     ) ( 1292.       ) ( 1265.81     ) ( 26.1808     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 250.617         162.78          9.75256         913935.         .207305
( 1.27313     )                 ( 5.14448     ) ( 267.838     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 107724.         .636117         1.86            5.11153
                                ( .566928     ) ( 1.55799     )

*************************************************************************

                    RUN          14

    G2= 46000.
       ( 21.7096      )
    Y1= .001                          Y2= 1.97212E-02

    X1= .5625                         X2= .04493

    T3= 240                           T2= 93
       ( 388.556      )                  ( 306.889      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 155.8           4.47777E+06     4.37014E+06     107629.         2.40363
( 341.778     ) ( 1312.26     ) ( 1280.71     ) ( 31.5418     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 258.564         156.799         9.69078         1.11195E+06     .248026
( 1.31051     )                 ( 5.11189     ) ( 325.867     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 96920.6         .641405         1.86            5.18387
                                ( .566928     ) ( 1.58102     )

*************************************************************************

                    RUN          15

    G2= 46000.
       ( 21.7096      )
    Y1= .001                          Y2= 1.97212E-02

    X1= .5625                         X2= .04493

    T3= 260                           T2= 96.5
       ( 399.667      )                  ( 308.833      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 174.5           4.54691E+06     4.41099E+06     127920.         2.8134
( 352.167     ) ( 1332.52     ) ( 1295.83     ) ( 37.4891     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 266.595         135.371         9.67574         1.31585E+06     .299394
( 1.3543      )                 ( 5.10396     ) ( 385.620     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 92270.          .645905         1.86            5.25282
                                ( .566928     ) ( 1.60106     )

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                      RUN          16

     G2= 46000.
        ( 21.7096      )
     Y1= .0214                          Y2= 4.05027E-02

     X1= .5625                          X2= .04493

     T3= 220                            T2= 104
        ( 377.444      )                   ( 313  )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 137.8           4.44767E+06     4.38061E+06     67061.          1.50778
( 331.778      ) ( 1303.43     ) ( 1283.78     ) ( 19.6529     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 253.859         162.98          9.75256         790591.         .177754
( 1.2896       )                ( 5.14443      ) ( 231.691     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106353.         .63783          1.86            5.13571
                                ( .566928      ) ( 1.56536     )

****************************************************************

                      RUN          17

     G2= 46000.
        ( 21.7096      )
     Y1= .0214                          Y2= 4.05027E-02

     X1= .5625                          X2= .04493

     T3= 240                            T2= 107
        ( 388.556      )                   ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 156.6           4.51259E+06     4.42764E+06     84959.          [illegible]
( 342.222      ) ( 1322.46     ) ( 1297.56     ) ( 24.8981     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 262.[illegible]        158.[illegible]         9.69078         1.00[illegible]E+06    .222927
( 1.33469      )                ( 5.11189      ) ( 294.812     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 95367.0         .640636         1.86            5.21739
                                ( .566928      ) ( 1.59087     )

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                      RUN          18

     G2= 46000.
        ( 21.7096      )
     Y1= .0214                          Y2= 4.05027E-02

     X1= .5625                          X2= .04493

     T3= 260                            T2= 109
        ( 399.667      )                   ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 175.0           4.58274E+06     4.47040E+06     112457.         2.45[illegible]
( 352.611      ) ( 1343.08     ) ( 1310.12     ) ( 32.9566     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 271.679         155.571         9.67574         1.22622E+06     .267[illegible]
( 1.38813      )                ( 5.10396      ) ( 359.357     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 [illegible]         .640464         1.86            5.29107
                                ( .566928      ) ( 1.61272     )

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RUN
FLUID2

                    RUN         1

     G2= 42000.
        ( 19.8218     )
     Y1= .001                         Y2= .025605

     X1= .5625                        X2= .04493

     T3= 220                          T2= 89
        ( 377.444     )                  ( 304.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 112.2          5.23432E+06    5.12749E+06    106832.        2.04099
( 317.556    ) ( 1533.97    ) ( 1502.66    ) ( 31.3082    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 221.737        148.807        8.76787        615397.        .11757
( 1.12642    )                ( 4.62505    ) ( 180.348    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 111155.        .611084        2.232          5.73902
                              ( .680313    ) ( 1.74925    )

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                    RUN         2

     G2= 42000.
        ( 19.8218     )
     Y1= .001                         Y2= .025605

     X1= .5625                        X2= .04493

     T3= 240                          T2= 93
        ( 388.556     )                  ( 306.889     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 130.5          5.31686E+06    5.18760E+06    129259.        2.43111
( 327.722    ) ( 1553.16    ) ( 1520.28    ) ( 37.8805    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 227.545        143.347        8.71201        807766.        .151925
( 1.15607    )                ( 4.59575    ) ( 236.724    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 99649.8        .616759        2.232          5.82401
                              ( .680313    ) ( 1.77516    )

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                    RUN         3

     G2= 42000.
        ( 19.8218     )
     Y1= .001                         Y2= .025605

     X1= .5625                        X2= .04493

     T3= 260                          T2= 96.5
        ( 399.667     )                  ( 308.833     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 148.6          5.40912E+06    5.24487E+06    164246.        3.03646
( 337.778    ) ( 1585.2     ) ( 1537.06    ) ( 48.1339    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 237.127        142.044        8.69881        996779.        .184277
( 1.20461    )                ( 4.50862    ) ( 292.116    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 94728.2        .621277        2.232          5.89349
                              ( .680313    ) ( 1.79634    )

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                    RUN         4

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                      Y2= 4.65064E-02

     X1= .5625                      X2= .04493

     T3= 220                        T2= 104
        ( 377.444     )                ( 313   )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 112.6           5.30586E+06     5.20038E+06     105482.         1.98803
( 317.778     ) ( 1554.94     ) ( 1524.02     ) ( 30.9126     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 221.863         148.807         8.76787         441562.         8.32215E-02
( 1.12786     )                 ( 4.62525     ) ( 129.404     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 111092.         .611156         2.232           5.7401
                                ( .680313     ) ( 1.74958     )

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                    RUN         5

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                      Y2= 4.65064E-02

     X1= .5625                      X2= .04493

     T3= 240                        T2= 107
        ( 388.556     )                ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 131.6           5.35527E+06     5.25726E+06     98002.          1.83001
( 328.333     ) ( 1569.41     ) ( 1540.69     ) ( 28.7205     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 232.141         140.547         8.71231         688937.         .128647
( 1.17927     )                 ( 4.59575     ) ( 201.9       )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 90559.6         .618212         2.232           5.84617
                                ( .680313     ) ( 1.78191     )

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                    RUN         6

     G2= 42000.
        ( 19.8218     )
     Y1= .0214                      Y2= 4.65064E-02

     X1= .5625                      X2= .04493

     T3= 260                        T2= 109
        ( 399.667     )                ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 149.9           5.43925E+06     5.30778E+06     131469.         2.41704
( 338.5       ) ( 1594.03     ) ( 1555.5      ) ( 38.5290     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 241.875         142.044         8.69881         905017.         .166386
( 1.22466     )                 ( 4.58862     ) ( 265.224     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 93181.8         .625420         2.232           5.92715
                                ( .680313     ) ( 1.8066      )

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                   RUN         7

     G2= 44000.
       ( 20.7657     )
     Y1= .001                         Y2= 2.44866E-02

     X1= .5625                        X2= .04493

     T3= 220                          T2= 89
       ( 377.444     )                  ( 304.667     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 116.9           5.24449E+06    5.13800E+06    106498.        2.03066
( 320.167     ) ( 1536.95     ) ( 1505.74     ) ( 31.2103     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 233.918         155.894        9.25032        696450.        .132796
( 1.1883      )               ( 4.88076     ) ( 204.102     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 110087.         .622044        2.232          5.91327
                              ( .680313     ) ( 1.80236     )

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                   RUN         8

     G2= 44000.
       ( 20.7657     )
     Y1= .001                         Y2= 2.44866E-02

     X1= .5625                        X2= .04493

     T3= 240                          T2= 93
       ( 388.556     )                  ( 306.889     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 135.4           5.32080E+06    5.19856E+06    122235.        2.29731
( 330.444     ) ( 1559.31     ) ( 1523.49     ) ( 35.8222     )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 241.949         150.173        9.19966        895675.        .168335
( 1.2291      )               ( 4.85202     ) ( 262.487     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 99045.3         .62817         2.232          6.00274
                              ( .680313     ) ( 1.82964     )

*****************************************************************

                   RUN         9

     G2= 44000.
       ( 20.7657     )
     Y1= .001                         Y2= 2.44866E-02

     X1= .5625                        X2= .04493

     T3= 260                          T2= 96.5
       ( 399.667     )                  ( 308.833     )


T4             Q IN           Q REQ          Q LOSS         % LOSS
 153.6           5.41206E+06    5.25605E+06    156306.        2.88795
( 340.556     ) ( 1586.15     ) ( 1540.34     ) ( 45.807      )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 247.799         148.807        9.18538        1.09303E+06    .201951
( 1.20078     )               ( 4.04529     ) ( 322.324     )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 942[illegible].4        .632606        2.232          6.07655
                              ( .680313     ) ( 1.85213     )

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                    RUN         10

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                        Y2= 4.53652E-02

    X1= .5625                        X2= .04493

    T3= 220                          T2= 104
       ( 377.444     )                  ( 313  )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 117.3           5.31527E+06     5.21089E+06     104384.         1.96385
( 320.389     ) ( 1557.69     ) ( 1527.1      ) ( 30.5908     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 235.011         155.894         9.25832         535107.         .100674
( 1.19386     )                 ( 4.88376     ) ( 156.819     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 109875.         .623152         2.232           5.9228
                                ( .680313     ) ( 1.80527     )

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                    RRUN        11

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                        Y2= 4.53652E-02

    X1= .5625                        X2= .04493

    T3= 240                          T2= 107
       ( 388.556     )                  ( 314.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 136.3           5.36703E+06     5.26777E+06     99258.          1.8494
( 330.944     ) ( 1572.86     ) ( 1543.77     ) ( 29.0885     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 244.953         150.173         9.19966         775855.         .144557
( 1.24436     )                 ( 4.85282     ) ( 227.372     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 97834.7         .629795         2.232           6.02907
                                ( .680313     ) ( 1.83767     )

*****************************************************************

                    RUN         12

    G2= 44000.
       ( 20.7657     )
    Y1= .0214                        Y2= 4.53652E-02

    X1= .5625                        X2= .04493

    T3= 260                          T2= 109
       ( 399.667     )                  ( 315.778     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 154.6           5.45581E+06     5.31829E+06     136723.         2.50637
( 341.111     ) ( 1570.65     ) ( 1558.58     ) ( 40.068      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 254.041         148.807         9.18538         997472.         .182954
( 1.27858     )                 ( 4.84529     ) ( 292.319     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 92633.5         .63492          2.232           6.11573
                                ( .680313     ) ( 1.86347     )

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                    RUN         13

     G2= 46000.
        ( 21.7096     )
     Y1= .001                          Y2= 2.34654E-02

     X1= .5625                         X2= .04493

     T3= 220                           T2= 89
        ( 377.444     )                   ( 304.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 121.2           5.25420E+06     5.14761E+06     106594.          2.02874
( 322.556     ) ( 1539.8      ) ( 1508.56     ) ( 31.2384     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 245.984         162.98          9.75256         775601.          .147612
( 1.2496      )                 ( 5.14448     ) ( 227.292     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 109746.         .656697         2.232           6.09233
                                ( .680313     ) ( 1.85694     )

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                    RUN         14

     G2= 46000.
        ( 21.7096     )
     Y1= .001                          Y2= 2.34654E-02

     X1= .5625                         X2= .04493

     T3= 240                           T2= 93
        ( 388.556     )                   ( 306.889     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 139.6           5.33929E+06     5.20795E+06     131341.          2.45987
( 332.778     ) ( 1564.73     ) ( 1526.24     ) ( 38.4909     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 254.187         156.999         9.69079         980415.          .180620
( 1.29127     )                 ( 5.11107     ) ( 287.32      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 98563.6         .639197         2.232           6.18619
                                ( .680313     ) ( 1.88555     )

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                    RUN         15

     G2= 46000.
        ( 21.7096     )
     Y1= .001                          Y2= 2.34654E-02

     X1= .5625                         X2= .04493

     T3= 260                           T2= 96.5
        ( 399.667     )                   ( 308.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 158.2           5.41375E+06     5.26634E+06     147406.          2.72281
( 343.111     ) ( 1586.55     ) ( 1543.35     ) ( 43.1988     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 262.43          155.571         9.67579         1.18935E+06      .2.717
( 1.33315     )                 ( 5.10375     ) ( 348.55      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 93749.6         .64378          2.232           6.26578
                                ( .680313     ) ( 1.79781     )

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                    RUN        16

     C2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .Ø214                         Y2= 4.4Ø2Ø3E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 22Ø                           T2= 1Ø4
        ( 377.444     )                   ( 313  )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 121.6           5.32421E+Ø6    5.22Ø51E+Ø6    1Ø37Ø8.        1.94786
( 322.778     ) ( 156Ø.31     ) ( 1529.92     ) ( 3Ø.3927     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 247.754         162.98         9.75256        6199Ø2.        .116431
( 1.25859     )                ( 5.14448     ) ( 181.668     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 1Ø8965.         .634589        2.232          6.1Ø819
                               ( .68Ø313     ) ( 1.86178     )

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                    RUN        17

     C2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .Ø214                         Y2= 4.4Ø2Ø3E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 24Ø                           T2= 1Ø7
        ( 388.556     )                   ( 314.667     )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 14Ø.8           5.3675ØE+Ø6    5.27783E+Ø6    89666.         1.67Ø54
( 333.444     ) ( 1573.       ) ( 1546.72     ) ( 26.2775     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 257.725         156.999        9.69Ø78        862873.        .16Ø759
( 1.3Ø924     )                ( 5.11189     ) ( 252.874     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 97215.1         .641Ø49        2.232          6.21811
                               ( .68Ø313     ) ( 1.89528     )

*****************************************************************

                    RUN        18

     C2= 46ØØØ.
        ( 21.7Ø96     )
     Y1= .Ø214                         Y2= 4.4Ø2Ø3E-Ø2

     X1= .5625                         X2= .Ø4493

     T3= 26Ø                           T2= 1Ø9
        ( 399.667     )                   ( 315.778     )

T4              Q IN           Q REQ          Q LOSS         % LOSS
 159.2           5.454Ø7E+Ø6    5.32857E+Ø6    125496.        2.3ØØ96
( 343.667     ) ( 1598.37     ) ( 1561.59     ) ( 36.7779     )

FLUID VEL       REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 267.95          155.571        9.67573        1.Ø9187E+Ø6    .2ØØ233
( 1.35661     )                ( 5.1Ø095     ) ( 32Ø.Ø47     )

ARCHIMEDES NO   BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 92133.1         .646185        2.232          6.3Ø75
                               ( .68Ø313     ) ( 1.9225Ø     )

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RUN
FLUID2

                              RUN          1

    G2= 52200.
       ( 24.6356      )
    Y1= .001                              Y2= 1.74976E-02

    X1= .5625                             X2= .04493

    T3= 220                               T2= 89
       ( 377.444      )                      ( 304.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 146.4           4.44161E+06     4.33663E+06     104980.         2.36356
( 336.556     ) ( 1301.66     ) ( 1270.89     ) ( 30.7654     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 287.078         184.946         11.3075         1.14373E+06     .257583
( 1.45835     )                 ( 5.96471     ) ( 335.182     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106721.         .66815          1.86            5.60495
                                ( .566928     ) ( 1.70839     )

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                              RUN          2

    G2= 52200.
       ( 24.6356      )
    Y1= .001                              Y2= 1.74976E-02

    X1= .5625                             X2= .04493

    T3= 240                               T2= 93
       ( 388.556      )                      ( 306.889      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 165.3           4.50779E+06     4.38785E+06     120147.         2.66524
( 347.056     ) ( [illegible]   ) ( 1285.9      ) ( 35.2[illegible] )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 296.[illegible]  178.159        11.2357         1.37168E+06     .304257
( 1.50386     )                 ( 5.92692     ) ( 401.96      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 96045.6         .673602         1.86            5.69856
                                ( .566928     ) ( 1.73692     )

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                              RUN          3

    G2= 52200.
       ( 24.6356      )
    Y1= .001                              Y2= 1.74976E-02

    X1= .5625                             X2= .04493

    T3= 260                               T2= 96.5
       ( 399.667      )                      ( 308.833      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 184.2           4.57403E+06     4.43706E+06     137316.         3.00105
( 357.556     ) ( 1340.57     ) ( 1300.33     ) ( 40.2418     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 [illegible].114  176.54         11.2114         1.60741E+06     .351394
( 1.54998     )                 ( 5.91772     ) ( 471.068     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 91510.          .67016          1.86            5.77727
                                ( .566928     ) ( 1.76152     )

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                    RUN        4

     G2= 52000.
        ( 24.5412      )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 220                            T2= 104
        ( 377.444      )                   ( 313   )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 146.7           4.48342E+06     4.39719E+06     86234.          1.9234
( 336.722     ) ( 1313.91     ) ( 1288.64     ) ( 25.2717     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 290.042         184.200         11.2568         1.00343E+06     .223808
( 1.47341     )                 ( 5.93798     ) ( 294.064     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 105231.         .669162         1.86            5.62209
                                ( .566928     ) ( 1.71361     )

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                    RUN        5

     G2= 52000.
        ( 24.5412      )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 240                            T2= 107
        ( 388.556      )                   ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 165.8           4.50847E+06     4.44780E+06     93677.          2.0645
( 347.333     ) ( 1330.05     ) ( 1302.59     ) ( 27.4588     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 299.703         177.477         11.1355         1.24754E+06     .274862
( 1.5235      )                 ( 5.90036     ) ( 365.605     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94440.9         .675003         1.86            5.72322
                                ( .566928     ) ( 1.74444     )

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                    RUN        6

     G2= 52000.
        ( 24.5412      )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 260                            T2= 109
        ( 399.667      )                   ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 184.6           4.61187E+06     4.48781E+06     124866.         2.69014
( 357.778     ) ( 1351.56     ) ( 1315.2      ) ( 36.3589     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 307.058         175.865         11.1681         1.4[illegible]10E+06  .324807
( 1.57408     )                 ( 5.8912      ) ( 439.032     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 89767.1         .679725         1.86            5.81114
                                ( .566928     ) ( 1.77124     )

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                    RUN          7

     G2= 54500.
        ( 25.7211      )
     Y1= .001                          Y2= 1.68014E-02

     X1= .5625                         X2= .04493

     T3= 220                           T2= 89
        ( 377.444      )                  ( 304.667      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 149.7           4.42939E+06     4.34278E+06     86610.          1.95535
( 338.389      ) ( 1298.08      ) ( 1272.7       ) ( 25.3819      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 300.689         193.095         11.8926         1.23296E+06     .278350
( 1.5275       )                ( 6.27334      ) ( 361.33       )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106331.         .677329         1.86            5.80395
                                ( .566928      ) ( 1.76904      )

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                    RUN          8

     G2= 54500.
        ( 25.7211      )
     Y1= .001                          Y2= 1.68014E-02

     X1= .5625                         X2= .04493

     T3= 240                           T2= 93
        ( 388.556      )                  ( 306.889      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 168.6           4.49870E+06     4.39399E+06     104702.         2.32730
( 348.889      ) ( 1318.39      ) ( 1287.7       ) ( 30.684       )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 310.207         186.009         11.8172         1.47165E+06     .327127
( 1.57483      )                ( 6.23359      ) ( 431.28       )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 95759.          .685005         1.86            5.90485
                                ( .566928      ) ( 1.7998       )

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                    RUN          9

     G2= 54500.
        ( 25.7211      )
     Y1= .001                          Y2= 1.68014E-02

     X1= .5625                         X2= .04493

     T3= 260                           T2= 96.5
        ( 399.667      )                  ( 308.833      )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 187.5           4.56801E+06     4.44321E+06     124796.         2.73196
( 359.389      ) ( 1338.7       ) ( 1302.13      ) ( 36.5727      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 319.458         184.018         11.7709         1.71988E+06     .376317
( 1.62285      )                ( 6.22392      ) ( 503.778      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 71232.6         .697606         1.86            5.77238
                                ( .566928      ) ( 1.82648      )

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                    RUN        10

     C2= 54600.
        ( 25.7683     )
     Y1= .0214                        Y2= 3.74939E-02

     X1= .5625                        X2= .04493

     T3= 220                          T2= 104
        ( 377.444     )                  ( 313  )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 149.9           4.50208E+06     4.40315E+06     98923.          2.19738
( 338.5       ) ( 1319.38     ) ( 1290.39     ) ( 28.9918     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 305.619         193.45          11.9181         1.09497E+06     .243215
( 1.55255     )                 ( 6.28681     ) ( 320.893     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 104062.         .682055         1.86            5.85837
                                ( .566928     ) ( 1.7831      )

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                    RUN        11

     C2= 54600.
        ( 25.7683     )
     Y1= .0214                        Y2= 3.74939E-02

     X1= .5625                        X2= .04493

     T3= 240                          T2= 107
        ( 388.556     )                  ( 314.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 169.1           4.55346E+06     4.45093E+06     102533.         2.25176
( 349.167     ) ( 1334.44     ) ( 1304.39     ) ( 30.0483     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 315.93          186.351         11.8426         1.35227E+06     .296976
( 1.60492     )                 ( 6.24697     ) ( 396.296     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 94141.4         .687730         1.86            5.96025
                                ( .566928     ) ( 1.81668     )

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                    RUN        12

     C2= 54600.
        ( 25.7683     )
     Y1= .0214                        Y2= 3.74939E-02

     X1= .5625                        X2= .04493

     T3= 260                          T2= 109
        ( 399.667     )                  ( 315.778     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 188             4.62410E+06     4.49414E+06     129963.         2.81055
( 359.667     ) ( 1355.14     ) ( 1317.05     ) ( 38.087      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 326.261         184.657         11.8242         1.61787E+06     .34971
( 1.65791     )                 ( 6.23729     ) ( 473.986     )

ARCHIMEDES NO  BED VOIDAGE     PACKED HEIGHT  EXPANDED HEIGHT
 89492.2         .692709         1.86            6.05684
                                ( .566928     ) ( 1.84612     )

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                 RUN          13

     G2= 57000.
        ( 26.901       )
     Y1= .001                      Y2= 1.61083E-02

     X1= .5625                     X2= .04493

     T3= 220                       T2= 89
        ( 377.444      )              ( 304.667      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 152.6           4.44147E+06     4.34810E+06     93288.          2.10039
( 340   )       ( 1301.62     ) ( 1274.28     ) ( 27.339      )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 315.327         201.953         12.5333         1.32669E+06     .298704
( 1.60186     )                 ( 6.61133     ) ( 388.799     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106097.         .691522         1.86            6.02959
                                ( .566928     ) ( 1.83782     )

****************************************************************

                 RUN          14

     G2= 57000.
        ( 26.901       )
     Y1= .001                      Y2= 1.61083E-02

     X1= .5625                     X2= .04493

     T3= 240                       T2= 93
        ( 388.556      )              ( 306.889      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 171.5           4.51396E+06     4.39940E+06     114557.         2.53788
( 350.5       ) ( 1322.86     ) ( 1289.29     ) ( 33.5727     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 325.043         194.542         12.4539         1.57746E+06     .349462
( 1.65122     )                 ( 6.56944     ) ( 462.29      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 95519.4         .69703          1.86            6.13922
                                ( .566928     ) ( 1.87124     )

****************************************************************

                 RUN          15

     G2= 57000.
        ( 26.901       )
     Y1= .001                      Y2= 1.61083E-02

     X1= .5625                     X2= .04493

     T3= 260                       T2= 96.5
        ( 399.667      )              ( 308.833      )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 190.6           4.57327E+06     4.44899E+06     124282.         2.71757
( 361.111     ) ( 1340.24     ) ( 1303.82     ) ( 36.4221     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 334.972         192.773         12.4046         1.93744E+06     .402216
( 1.70166     )                 ( 6.55925     ) ( 539.067     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 91019.3         .701707         1.86            6.23553
                                ( .566928     ) ( 1.90059     )

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                    RUN         16

     G2= 57100.
        ( 26.9482     )
     Y1= .0214                     Y2= 3.67892E-02

     X1= .5625                     X2= .04493

     T3= 220                       T2= 104
        ( 377.444     )               ( 313  )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 152.9          4.50673E+06    4.40874E+06    97985.          2.17419
( 340.167    ) ( 1320.74    ) ( 1292.03    ) ( 28.7155    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 320.646        202.307        12.559         1.18520E+06    .262991
( 1.62888    )                ( 6.6249     ) ( 347.343    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 104525.        .694153        1.86           6.08147
                              ( .566928    ) ( 1.85363    )

*******************************************************************

                    RUN         17

     G2= 57100.
        ( 26.9482     )
     Y1= .0214                     Y2= 3.67892E-02

     X1= .5625                     X2= .04493

     T3= 240                       T2= 107
        ( 388.556     )               ( 314.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 172.1          4.56046E+06    4.45652E+06    103940.         2.27916
( 350.833    ) ( 1336.49    ) ( 1306.03    ) ( 30.4607    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 331.059        174.383        12.4795        1.45453E+06    .318944
( 1.68331    )                ( 6.58292    ) ( 426.264    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 93068.3        .738049        1.86           6.20102
                              ( .566928    ) ( 1.89007    )

*******************************************************************

                    RUN         18

     G2= 57100.
        ( 26.9482     )
     Y1= .0214                     Y2= 3.67892E-02

     X1= .5625                     X2= .04493

     T3= 260                       T2= 109
        ( 399.667     )               ( 315.778     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 191            4.63434E+06    4.49970E+06    134607.         2.90456
( 361.333    ) ( 1358.14    ) ( 1318.69    ) ( 39.4479    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 342.22         193.112        12.4601        1.72244E+06    .373827
( 1.73848    )                ( 6.57271    ) ( 507.709    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 89250.6        .765068        1.86           6.32634
                              ( .566928    ) ( 1.92228    )

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RUN
FLUID2

                    RUN          1

     G2= 62600.
        ( 29.5439     )
     Y1= .001                          Y2= 1.75081E-02

     X1= .5625                         X2= .04493

     T3= 220                           T2= 89
        ( 377.444     )                   ( 304.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 146.4           5.32653E+06     5.20396E+06     122575.         2.30122
( 336.556     ) ( 1560.99     ) ( 1525.07     ) ( 35.9218     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 344.276         221.794         13.9857         1.41462E+06     .265581
( 1.74892     )                 ( 7.37746     ) ( 414.57      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106720.         .715701         2.232           7.85089
                                ( .680313     ) ( 2.39295     )

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                    RUN          2

     G2= 62600.
        ( 29.5439     )
     Y1= .001                          Y2= 1.75081E-02

     X1= .5625                         X2= .04493

     T3= 240                           T2= 92
        ( 388.556     )                   ( 306.889     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 165.3           5.40614E+06     5.26541E+06     140727.         2.6031
( 347.056     ) ( 1584.32     ) ( 1543.08     ) ( 41.2414     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 355.018         213.655         13.8971         1.69646E+06     .313803
( 1.80349     )                 ( 7.33072     ) ( 497.165     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 96044.8         .721375         2.232           8.01076
                                ( .680313     ) ( 2.44168     )

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                    RUN          3

     G2= 62600.
        ( 29.5439     )
     Y1= .001                          Y2= 1.75081E-02

     X1= .5625                         X2= .04493

     T3= 260                           T2= 96.5
        ( 399.667     )                   ( 308.833     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 184.2           5.40575E+06     5.32447E+06     161277.         2.93993
( 357.556     ) ( 1607.65     ) ( 1560.39     ) ( 47.2638     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 365.706         211.713         13.8755         1.98813E+06     .362417
( 1.8598      )                 ( 7.31934     ) ( 582.641     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 91507.3         .726217         2.232           8.15244
                                ( .680313     ) ( 2.48486     )

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                    RUN        4

     G2= 62400.
        ( 29.4495     )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 220                            T2= 104
        ( 377.444     )                    ( 313  )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 146.7           5.38011E+06     5.27663E+06     103482.         1.92342
( 336.722     ) ( 1576.69     ) ( 1546.37     ) ( 30.3264     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 348.05          221.085         13.9334         1.24202E+06     .230853
( 1.76809     )                 ( 7.34989     ) ( 363.985     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 105231.         .716941         2.232           7.88528
                                ( .680313     ) ( 2.40343     )

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                    RUN        5

     G2= 62400.
        ( 29.4495     )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 240                            T2= 107
        ( 388.556     )                    ( 314.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 165.8           5.44617E+06     5.33372E+06     112439.         2.06455
( 347.333     ) ( 1596.05     ) ( 1563.1      ) ( 32.9514     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 359.883         212.972         13.8452         1.54418E+06     .283505
( 1.82821     )                 ( 7.30332     ) ( 452.[illegible]     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94440.9         .723030         2.232           8.05856
                                ( .680313     ) ( 2.45625     )

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                    RUN        6

     G2= 62400.
        ( 29.4495     )
     Y1= .0214                          Y2= 3.82986E-02

     X1= .5625                          X2= .04493

     T3= 260                            T2= 109
        ( 399.667     )                    ( 315.778     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 184.6           5.53425E+06     5.38537E+06     148881.         2.69019
( 357.778     ) ( 1621.97     ) ( 1578.24     ) ( 43.6311     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 371.83          211.036         13.8237         1.85431E+06     .33506
( 1.8889      )                 ( 7.29199     ) ( 543.420     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 [illegible]     .728264         2.232           8.21056
                                ( .680313     ) ( 2.50257     )

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                    RUN          7

    G2= 65400.
       ( 30.8653      )
    Y1= .001                          Y2= 1.68014E-02

    X1= .5625                         X2= .04493

    T3= 220                           T2= 89
       ( 377.444      )                  ( 304.667      )

T4               Q IN              Q REQ             Q LOSS            % LOSS
 149.7            5.31527E+06       5.21133E+06       103934.           1.95537
( 338.389      ) ( 1557.69      ) ( 1527.23      ) ( 30.4589      )

FLUID VEL        REYNOLDS NO       H T COEFF         HEAT TRANS        % TRAN
 360.827          231.715           14.7204           1.52612E+06       .287121
( 1.833        )                   ( 7.76499      ) ( 447.246      )

ARCHIMEDES NO    BED VOIDAGE       PACKED HEIGHT     EXPANDED HEIGHT
 106381.          .728254           2.232             8.21355
                                   ( .680313      ) ( 2.50349      )

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                    RUN          8

    G2= 65400.
       ( 30.8653      )
    Y1= .001                          Y2= 1.68014E-02

    X1= .5625                         X2= .04493

    T3= 240                           T2= 93
       ( 388.556      )                  ( 306.889      )

T4               Q IN              Q REQ             Q LOSS            % LOSS
 168.6            5.39844E+06       5.27279E+06       125644.           2.32741
( 348.889      ) ( 1582.07      ) ( 1545.24      ) ( 36.8212      )

FLUID VEL        REYNOLDS NO       H T COEFF         HEAT TRANS        % TRAN
 372.020          223.211           14.6271           1.82157E+06       .337425
( 1.8898       )                   ( 7.71578      ) ( 5[illegible]   )

ARCHIMEDES NO    BED VOIDAGE       PACKED HEIGHT     EXPANDED HEIGHT
 95759.           .733957           2.232             8.38963
                                   ( .680313      ) ( 2.55716      )

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                    RUN          9

    G2= 65400.
       ( 30.8653      )
    Y1= .001                          Y2= 1.68014E-02

    X1= .5625                         X2= .04493

    T3= 260                           T2= 96.5
       ( 399.667      )                  ( 308.833      )

T4               Q IN              Q REQ             Q LOSS            % LOSS
 187.5            5.48161E+06       5.33185E+06       149758.           2.73201
( 359.389      ) ( 1606.44      ) ( 1562.55      ) ( 43.8881      )

FLUID VEL        REYNOLDS NO       H T COEFF         HEAT TRANS        % TRAN
 383.35           221.182           14.6044           2.12777E+06       .388165
( 1.94742      )                   ( 7.70381      ) ( 623.564      )

ARCHIMEDES NO    BED VOIDAGE       PACKED HEIGHT     EXPANDED HEIGHT
 91252.6          .738846           2.232             8.54669
                                   ( .680313      ) ( 2.60503      )

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                    RUN          1Ø

     G2= 655ØØ.
        ( 3Ø.9125      )
     Y1= .Ø214                        Y2= 3.74988E-Ø2

     X1= .5625                        X2= .Ø4493

     T3= 22Ø                          T2= 1Ø4
        ( 377.444      )                 ( 313   )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 149.9           5.4ØØ85E+Ø6     5.28378E+Ø6     117Ø65.         2.16753
( 338.5      ) ( 1582.77     ) ( 1548.47     ) ( 34.3Ø71     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 366.633         232.Ø69         14.7467         1.35485E+Ø6    .25Ø859
( 1.86249    )                 ( 7.77888     ) ( 397.Ø52     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 1Ø4861.         .73Ø884         2.232           8.29381
                               ( .68Ø313     ) ( 2.52795     )

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                    RUN          11

     G2= 655ØØ.
        ( 3Ø.9125      )
     Y1= .Ø214                        Y2= 3.74988E-Ø2

     X1= .5625                        X2= .Ø4493

     T3= 24Ø                          T2= 1Ø7
        ( 388.556      )                 ( 314.667     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 169.1           5.46248E+Ø6     5.34111E+Ø6     121373.         2.22194
( 347.167    ) ( 16ØØ.Ø4     ) ( 1565.27     ) ( 35.5696     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 379.ØØ1         223.553         14.6533         1.67321E+Ø6    .3Ø63Ø9
( 1.9253Ø    )                 ( 7.72959     ) ( 49Ø.35      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 94141.          .737Ø18         2.232           8.48726
                               ( .68Ø313     ) ( 2.58692     )

******************************************************************

                    RUN          12

     G2= 655ØØ.
        ( 3Ø.9125      )
     Y1= .Ø214                        Y2= 3.74988E-Ø2

     X1= .5625                        X2= .Ø4493

     T3= 26Ø                          T2= 1Ø9
        ( 399.667      )                 ( 315.778     )


T4              Q IN            Q REQ           Q LOSS          % LOSS
 188             5.54723E+Ø6     5.39297E+Ø6     154263.         2.78Ø9
( 359.667    ) ( 1625.67     ) ( 15Ø7.46     ) ( 45.2ØØØ     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 391.515         221.52          14.6Ø35         2.Ø83Ø9E+Ø6    .28Ø7
( 1.9289     )                 ( 7.71761     ) ( 586.Ø8      )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 87491.8         .742367         [illegible]     [illegible]
                               ( .68Ø313     ) ( 2.64ØØ3     )

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                    RUN         13

     G2= 68400.
        ( 32.2812     )
     Y1= .001                          Y2= 1.61083E-02

     X1= .5625                         X2= .04493

     T3= 220                           T2= 89
        ( 377.444     )                   ( 304.667     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 152.6           5.32976E+06     5.21782E+06     111947.          2.10041
( 340  )        ( 1561.94     ) ( 1529.13     ) ( 32.8072     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 378.392         242.344         15.5134         1.64214E+06     .308137
( 1.92223     )                 ( 8.18333     ) ( 481.245     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 106097.         .741301         2.232           8.62777
                                ( .680313     ) ( 2.62974     )

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                    RUN         14

     G2= 68400.
        ( 32.2812     )
     Y1= .001                          Y2= 1.61083E-02

     X1= .5625                         X2= .04493

     T3= 240                           T2= 93
        ( 388.556     )                   ( 306.889     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 171.5           5.41675E+06     5.27928E+06     137473.          2.53792
( 350.5       ) ( 1587.43     ) ( 1547.14     ) ( 40.2878     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 390.052         283.45          15.4151         1.95254E+06     .360463
( 1.98146     )                 ( 8.10148     ) ( 572.211     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 95519.4         .747843         2.232           8.82362
                                ( .680313     ) ( 2.68944     )

******************************************************************

                    RUN         15

     G2= 68400.
        ( 32.2812     )
     Y1= .001                          Y2= 1.61083E-02

     X1= .5625                         X2= .04493

     T3= 260                           T2= 96.5
        ( 399.667     )                   ( 308.833     )

T4              Q IN            Q REQ           Q LOSS          % LOSS
 190.6           5.48792E+06     5.33878E+06     149139.          2.71759
( 361.111     ) ( 1608.29     ) ( 1564.58     ) ( 43.7067     )

FLUID VEL       REYNOLDS NO     H T COEFF       HEAT TRANS      % TRAN
 401.967         231.328         15.3912         [illegible]7582E+06     .414875
( 2.04199     )                 ( 8.11907     ) ( 667.244     )

ARCHIMEDES NO   BED VOIDAGE     PACKED HEIGHT   EXPANDED HEIGHT
 91019.3         .752018         2.232           9.00864
                                ( .680313     ) ( 2.74339     )

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                    RUN        16

     G2= 68500.
        ( 32.3284     )
     Y1= .0214                      Y2= 3.67937E-02

     X1= .5625                      X2= .04493

     T3= 220                        T2= 104
        ( 377.444     )               ( 313  )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 152.9           5.40649E+06    5.29049E+06    116005.        2.14566
( 340.167    ) ( 1584.43    ) ( 1550.43    ) ( 33.9964    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 384.664        242.698        15.54          1.46654E+06    .271256
( 1.95409    )                ( 8.19733    ) ( 429.785    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 104525.        .744046        2.232          8.7203
                              ( .680313    ) ( 2.65795    )

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                    RUN        17

     G2= 68500.
        ( 32.3284     )
     Y1= .0214                      Y2= 3.67937E-02

     X1= .5625                      X2= .04493

     T3= 240                        T2= 107
        ( 388.556     )               ( 314.667     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 172.1           5.47095E+06    5.34782E+06    123132.        2.25065
( 350.833    ) ( 1603.32    ) ( 1567.20    ) ( 36.0851    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 397.517        233.792        15.4415        1.79977E+06    .3289[illegible]
( 2.01928    )                ( 8.1454     ) ( 527.409    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 93868.         .750203        2.232          8.93526
                              ( .680313    ) ( 2.72347    )

*****************************************************************

                    RUN        18

     G2= 68500.
        ( 32.3284     )
     Y1= .0214                      Y2= 3.67937E-02

     X1= .5625                      X2= .04493

     T3= 260                        T2= 107
        ( 399.667     )               ( 315.778     )

T4             Q IN           Q REQ          Q LOSS         % LOSS
 191             5.55958E+06    5.39968E+06    159907.        2.87624
( 361.333    ) ( 1629.29    ) ( 1582.43    ) ( 46.8628    )

FLUID VEL      REYNOLDS NO    H T COEFF      HEAT TRANS     % TRAN
 410.545        231.666        15.4175        2.14964E+06    .385775
( 2.08557    )                ( 8.13276    ) ( 628.214    )

ARCHIMEDES NO  BED VOIDAGE    PACKED HEIGHT  EXPANDED HEIGHT
 87253.3        .755541        2.232          9.13037
                              ( .680313    ) ( 2.78291    )

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VITA

The author, James Gerard Gerstle, is the son of Louis Bernard Gerstle and Mary Ann (Hellmann) Gerstle. He was born April 21, 1957, in Louisville, Kentucky.

His elementary education was obtained at Saint Stephen Martyr's in Louisville and his secondary education at Saint Xavier High School, also in Louisville. He was graduated in May, 1975.

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